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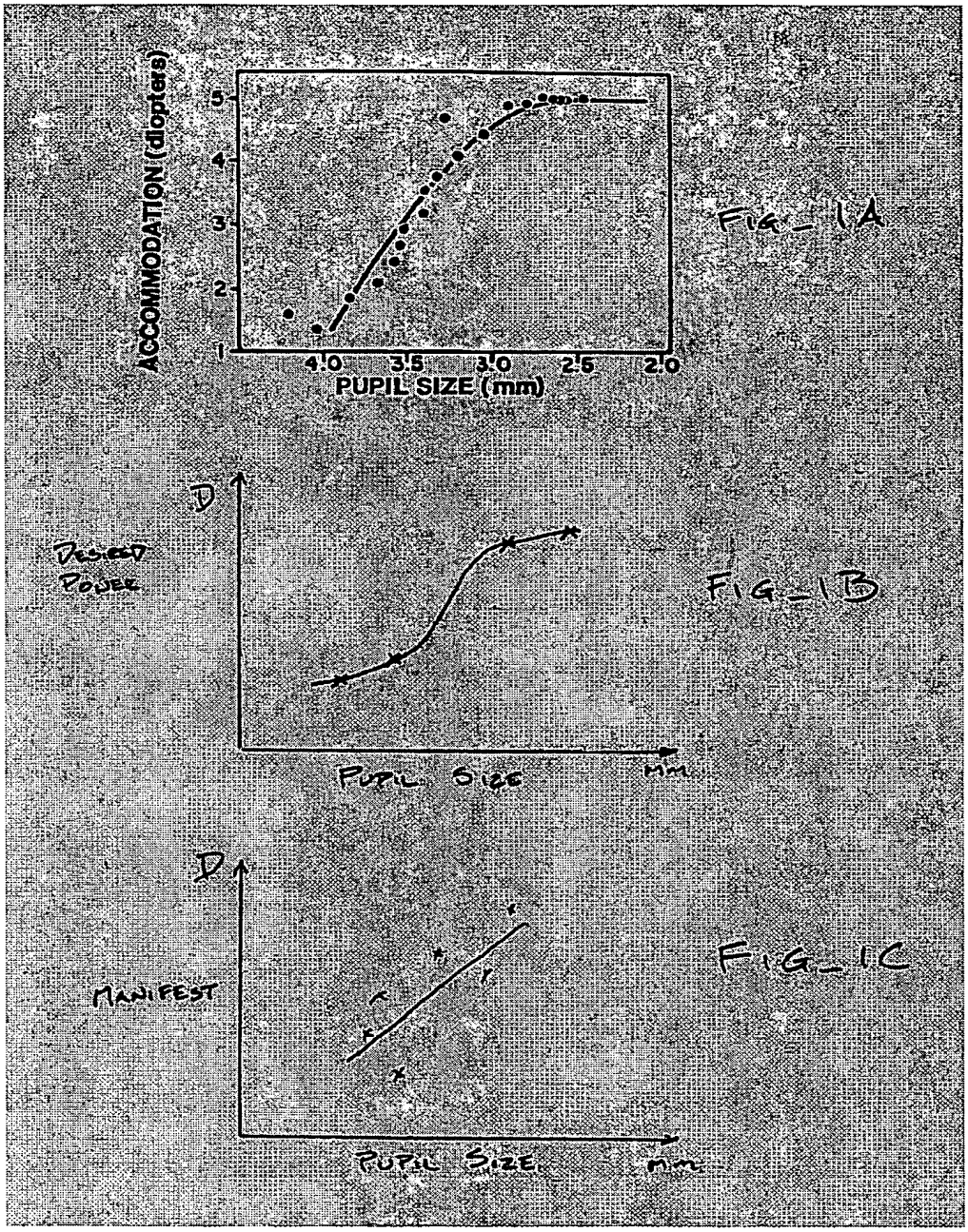

ACCOMMODATION (diopters)
5
4
3
2
1
4.0
3.5
3.0
2.5
2.0
PUPIL SIZE (mm)
FIG-1A
D
DESIRED POWER
PUPIL SIZE
mm
FIG-1B
D
MANIFEST
PUPIL SIZE
mm
FIG-1C

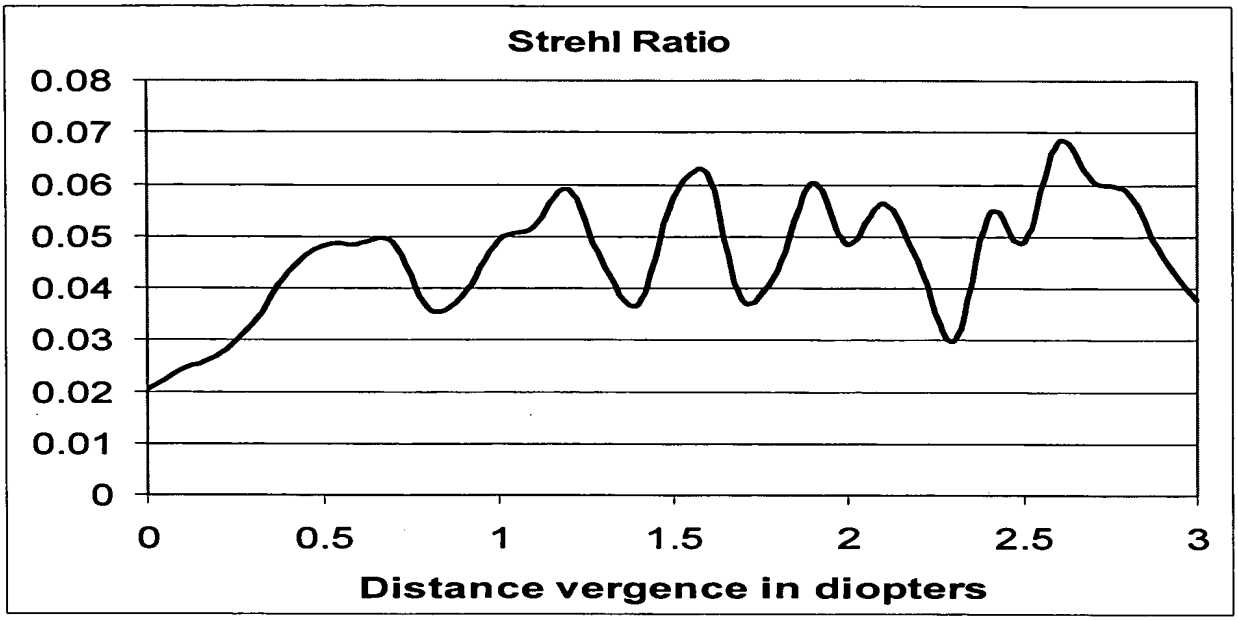

Strehl Ratio
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
3
Distance vergence in diopters

Fig. 2A

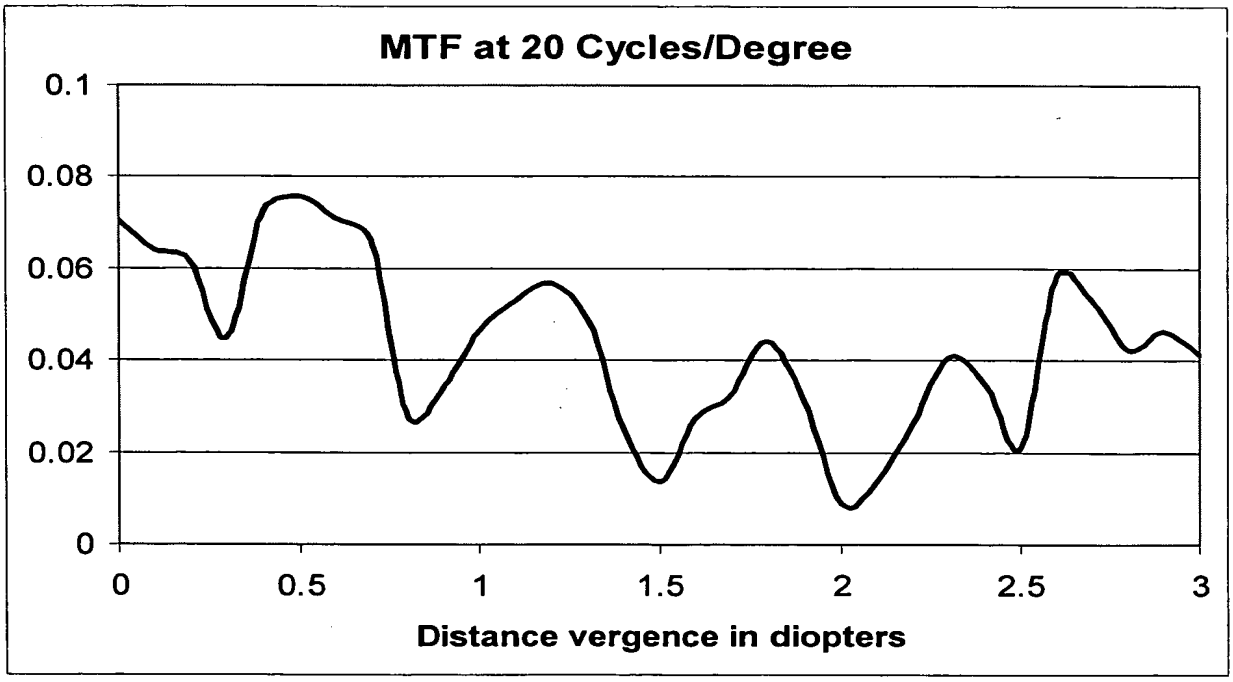

MTF at 20 Cycles/Degree
0.1
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
Distance vergence in diopters

Fig. 2B

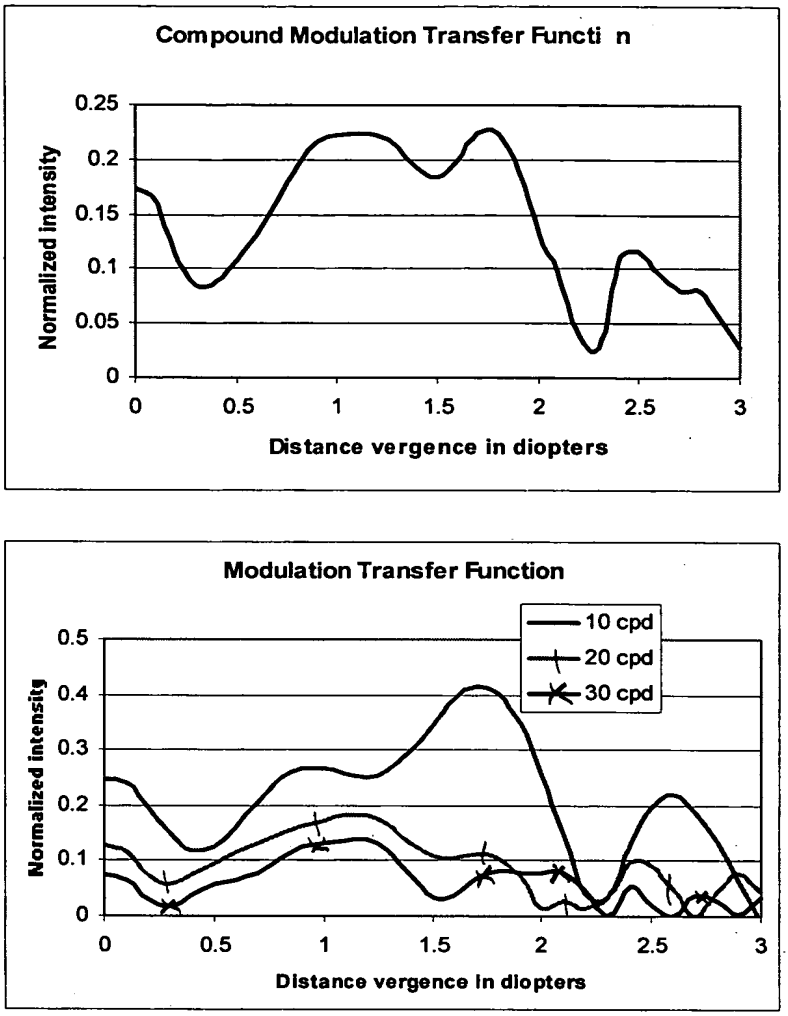


FIG. 2C

An example of the compound MTF (upper panel) versus its corresponding individual MTF curves at 10, 20, and 30 cpd (cycles per degree).

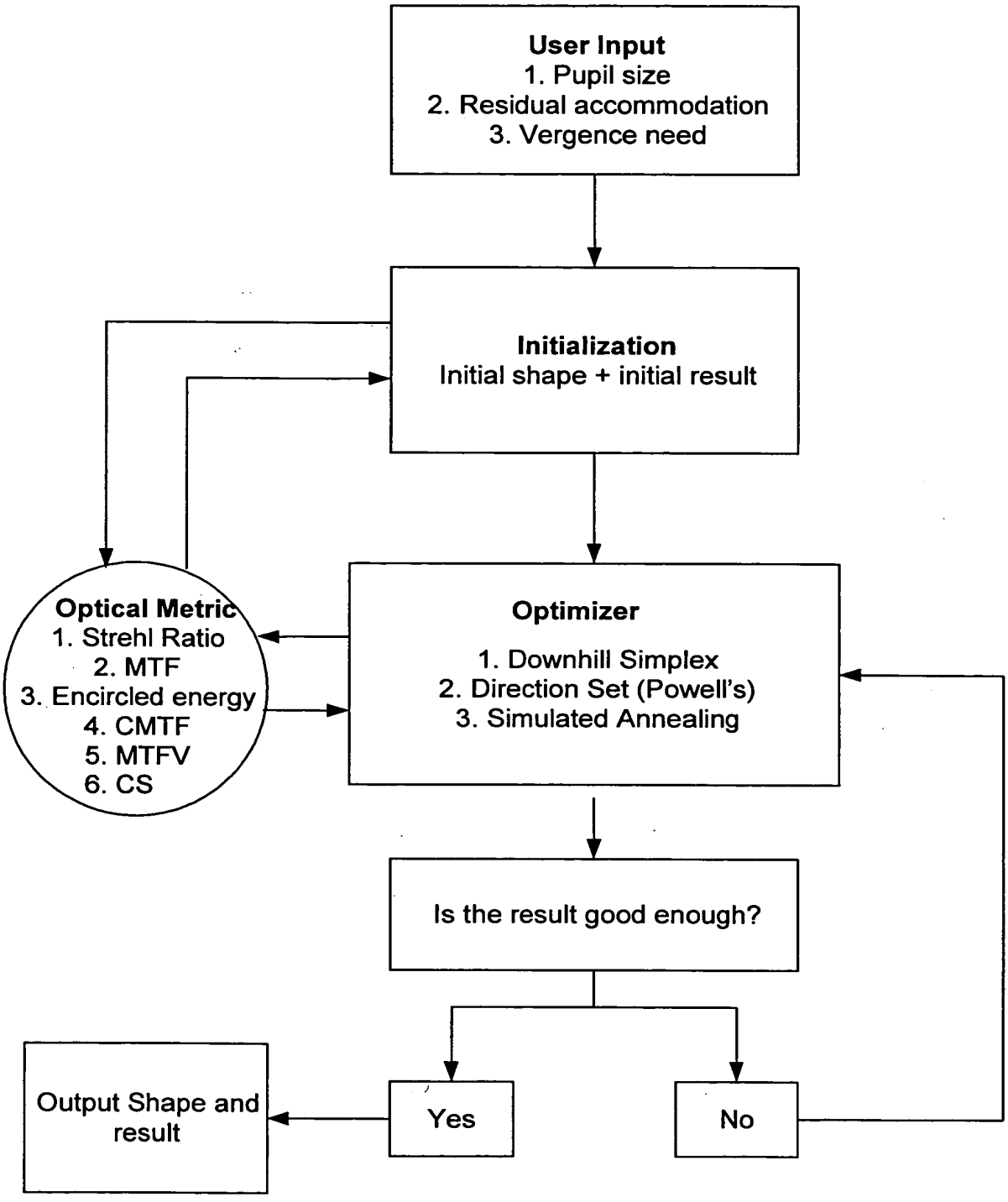

User Input
1. Pupil size
2. Residual accommodation
3. Vergence need
Initialization
Initial shape + initial result
Optical Metric
1. Strehl Ratio
2. MTF
3. Encircled energy
4. CMTF
5. MTFV
6. CS
Optimizer
1. Downhill Simplex
2. Direction Set (Powell's)
3. Simulated Annealing
Is the result good enough?
Yes
No
Output Shape and result

FIG. 3

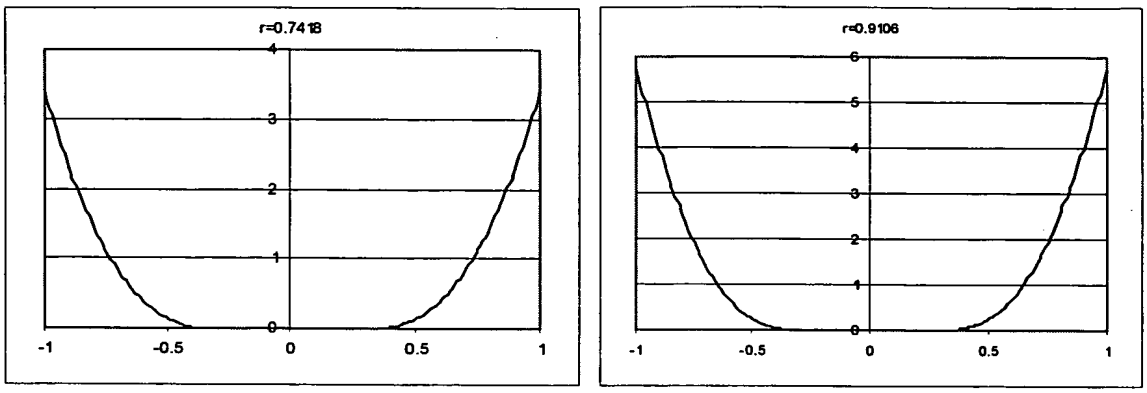
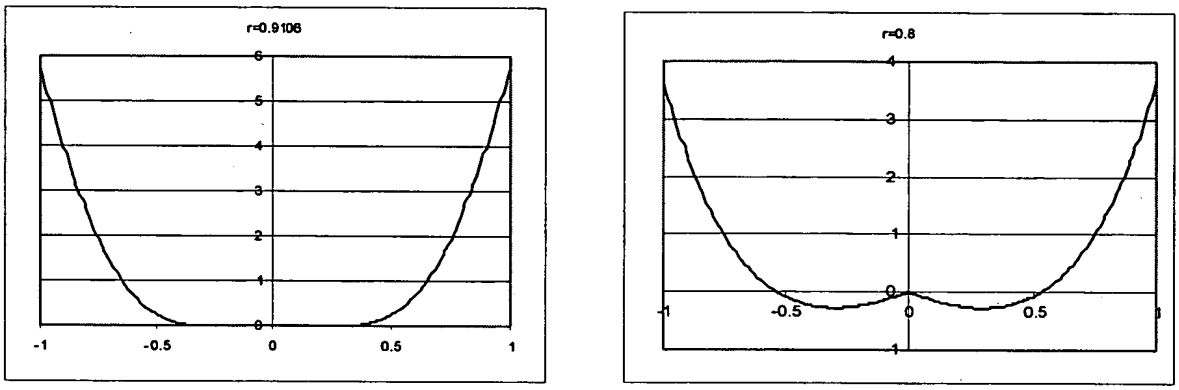


FIG. 4



Even-Power-Term Polynomials

Normal Polynomials

FIG. 5A

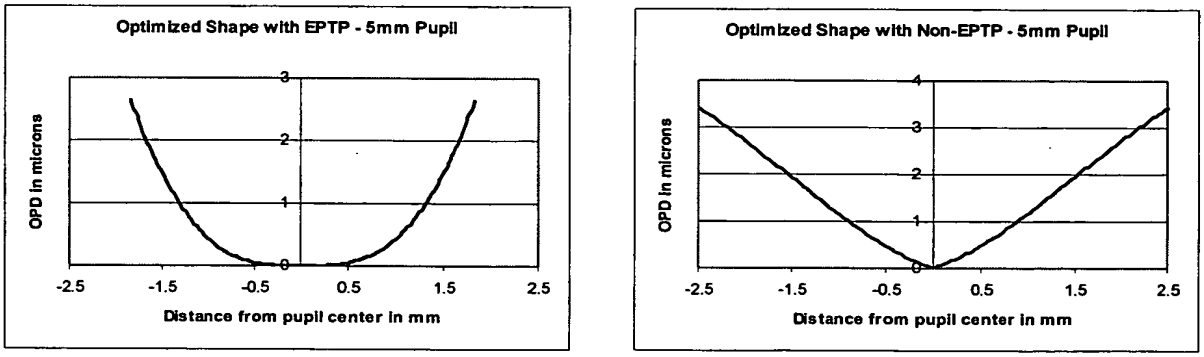
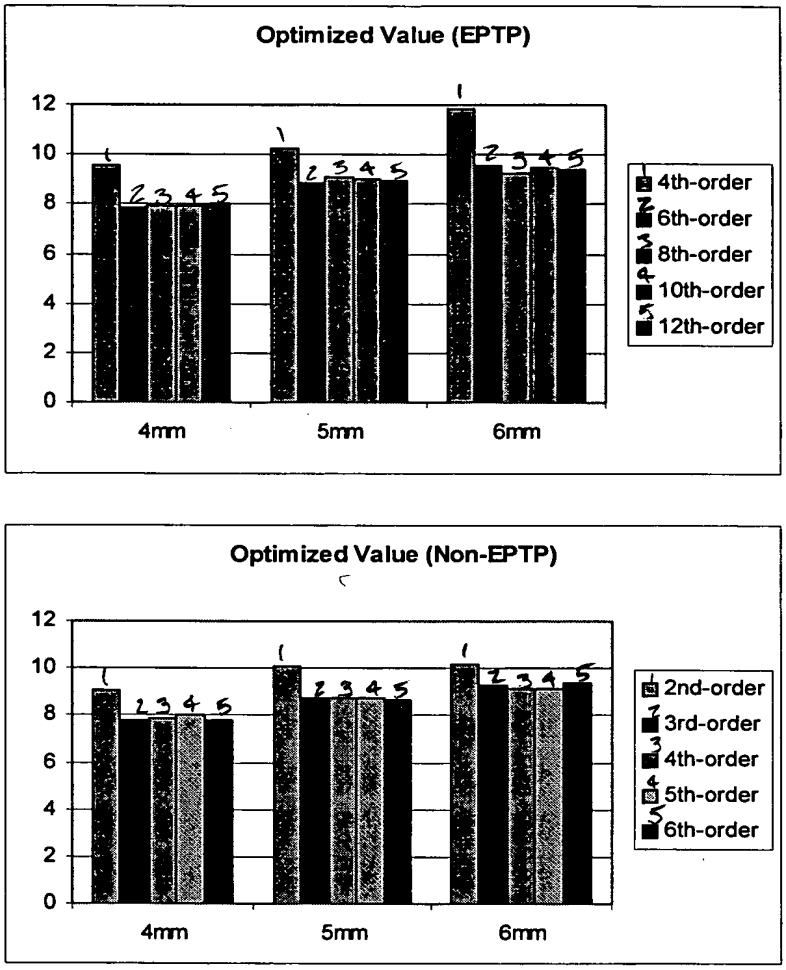


FIG. 5B



Comparison of the optimizer value using EPTP and non-EPTP (i.e., all power terms) for pupil sizes of 4mm, 5mm, and 6mm.

FIG. 5C

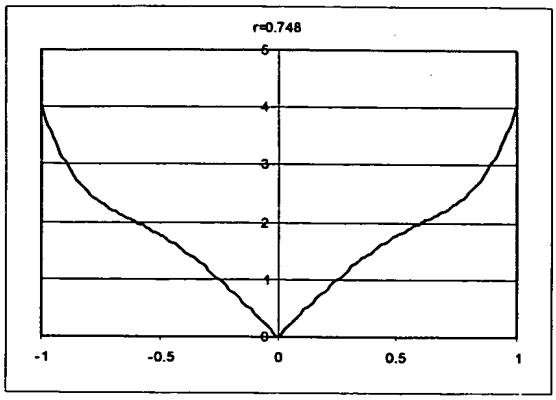


FIG. 6A

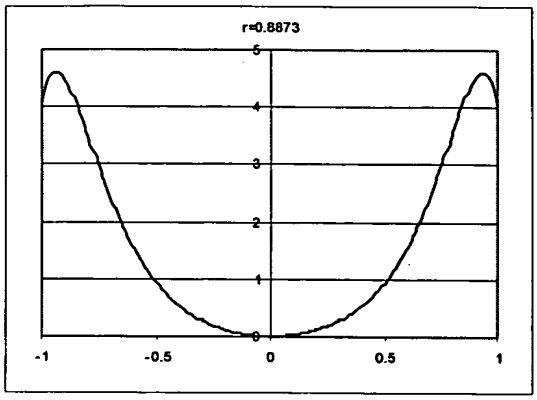


FIG. 6B

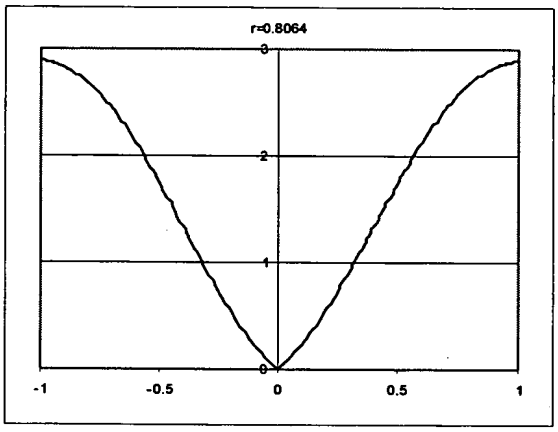


FIG. 6C

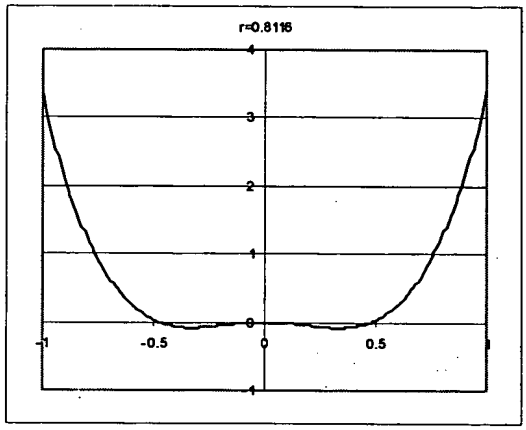


FIG. 6D

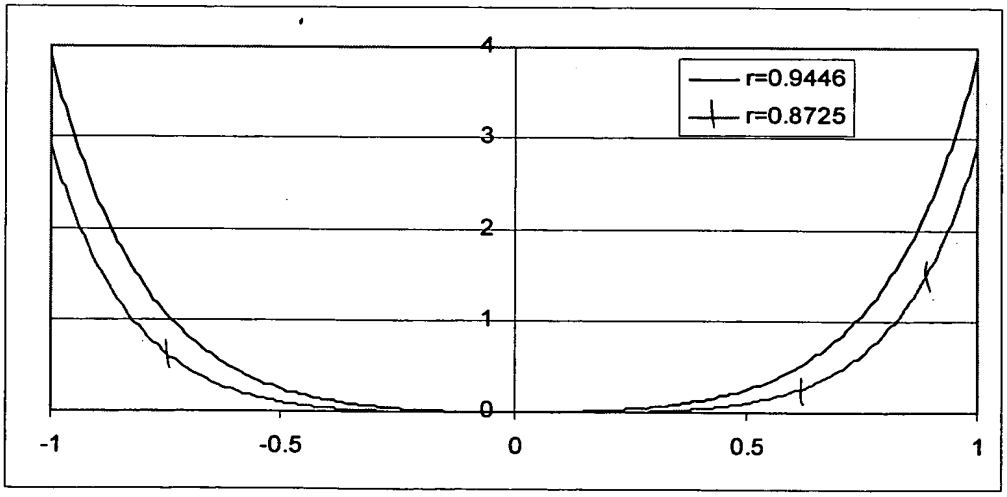


FIG. 7

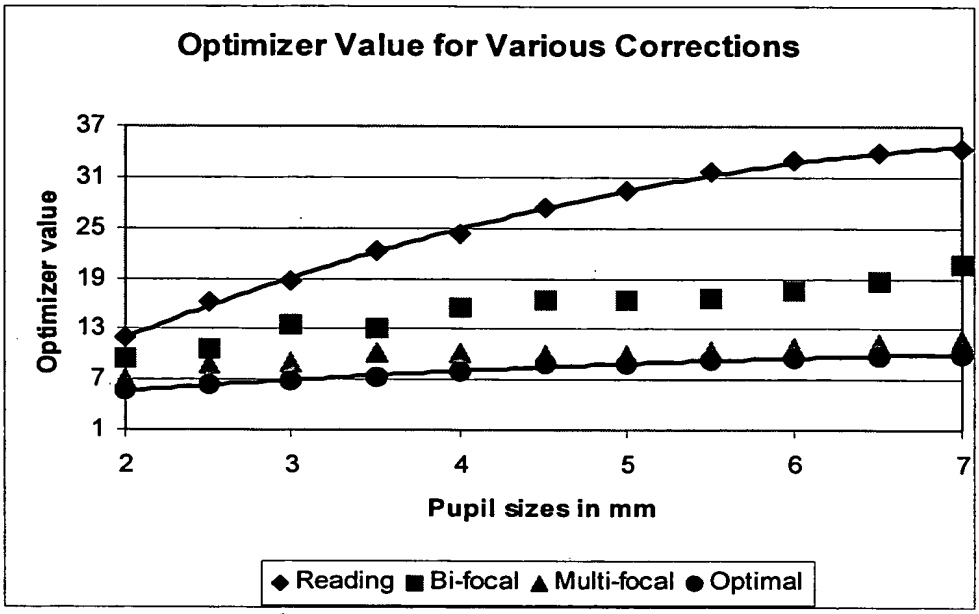

Optimizer Value for Various Corrections
Optimizer value
37
31
25
19
13
7
1
2
3
4
5
6
7
Pupil sizes in mm
Reading
Bi-focal
Multi-focal
Optimal

FIG. 8A

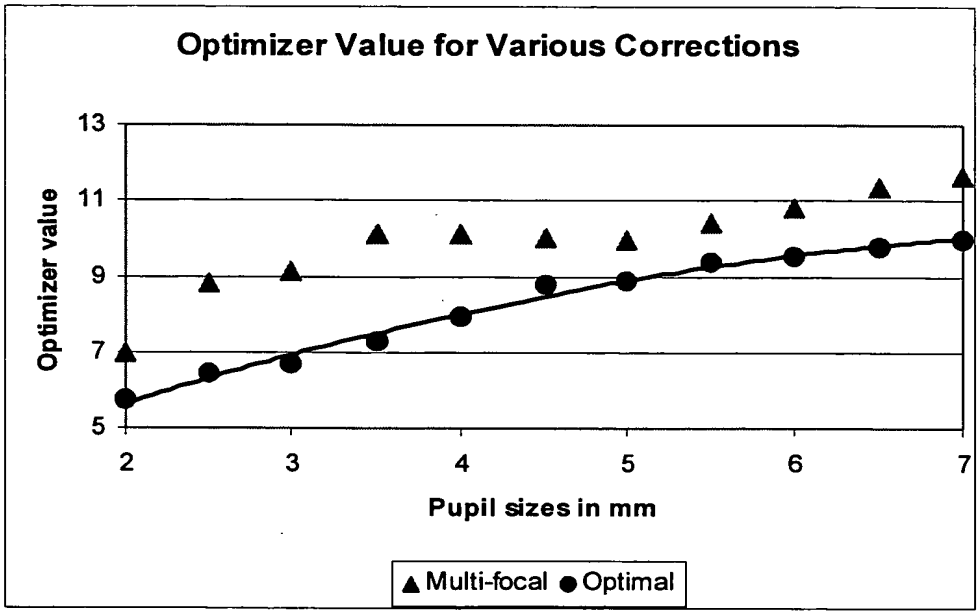

Optimizer Value for Various Corrections
Optimizer value
13
11
9
7
5
2
3
4
5
6
7
Pupil sizes in mm
Multi-focal
Optimal

FIG. 8B

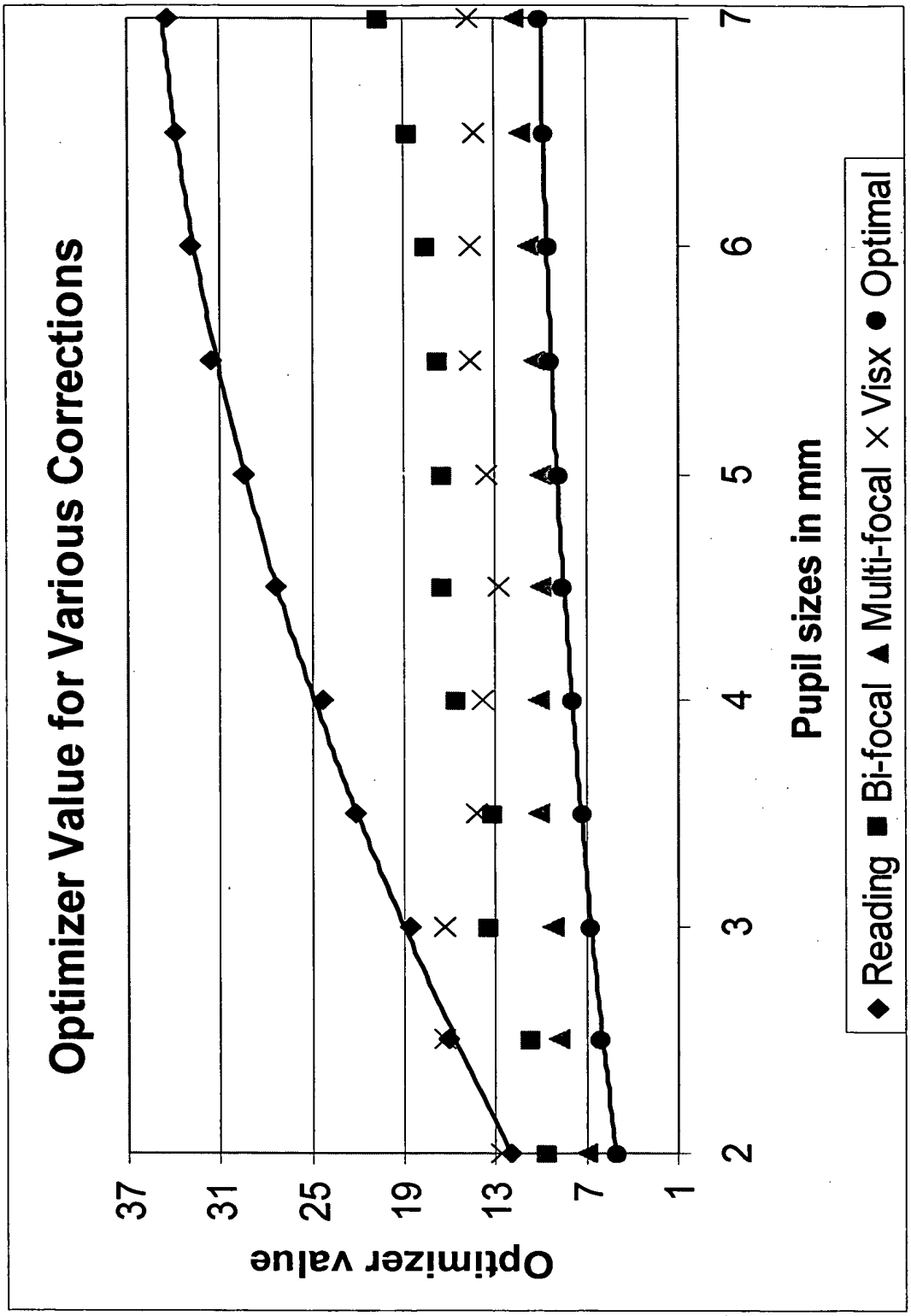

Optimizer Value for Various Corrections
Optimizer value
37
31
25
19
13
7
1
2
3
4
5
6
7
Pupil sizes in mm
◆ Reading ■ Bi-focal ▲ Multi-focal × Visx ● Optimal

FIG. 8C

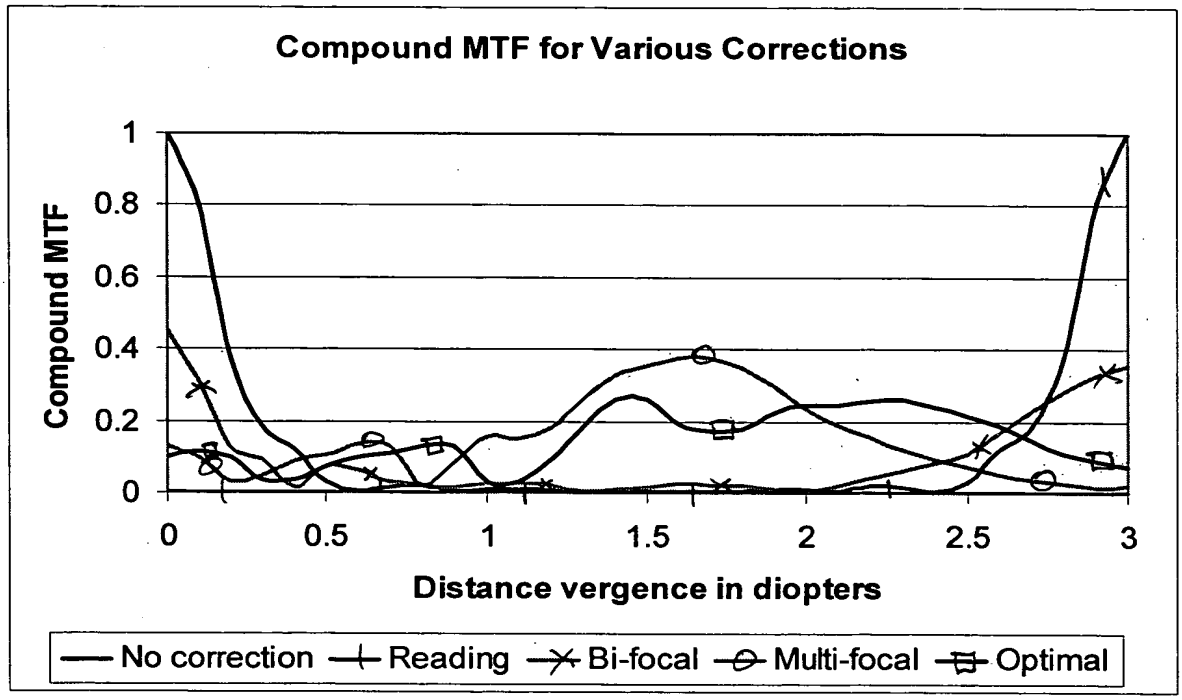

Compound MTF for Various Corrections
Compound MTF
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
Distance vergence in diopters
No correction
Reading
Bi-focal
Multi-focal
Optimal

FIG. 9A

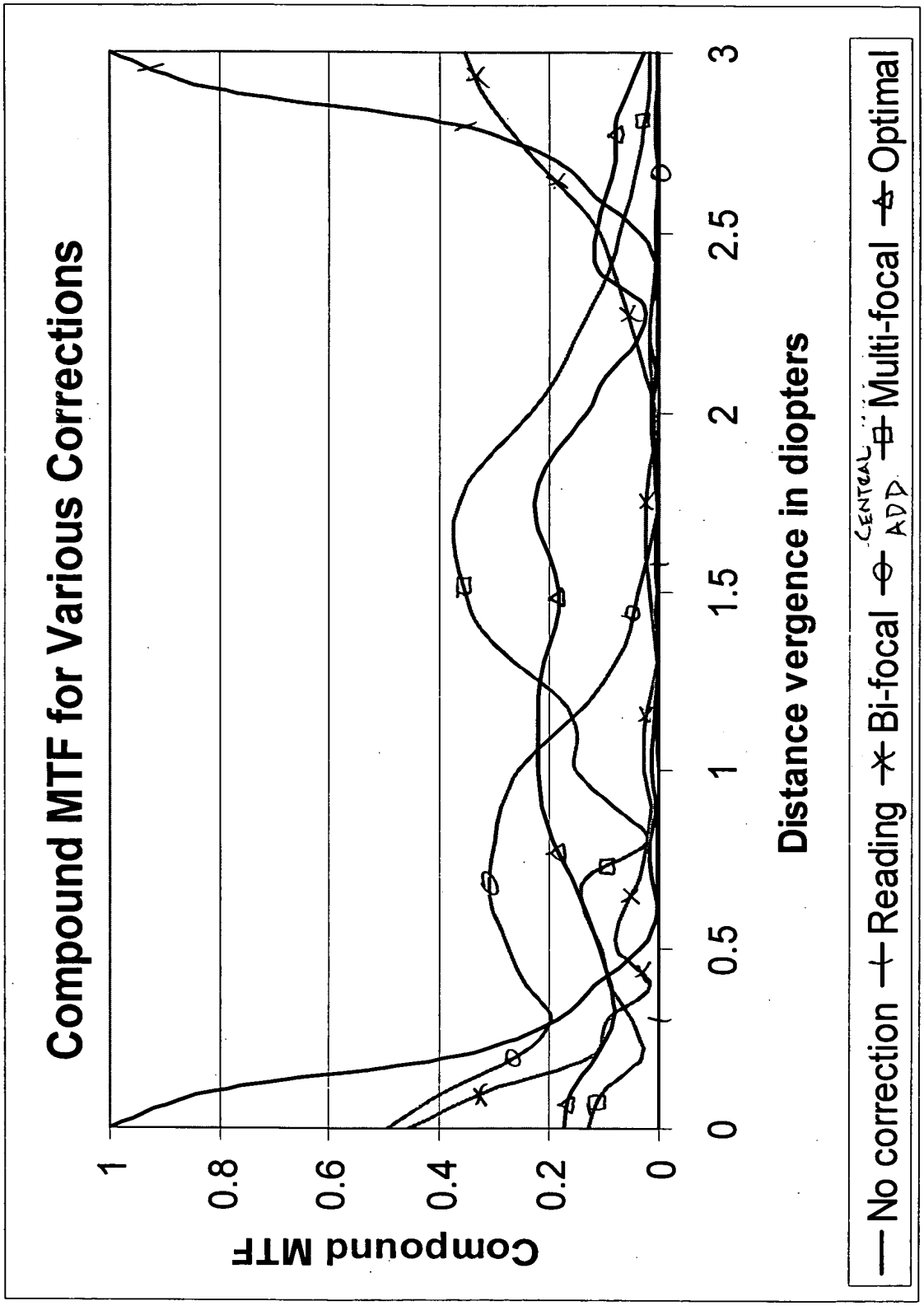

Compound MTF for Various Corrections
Compound MTF
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
Distance vergence in diopters
No correction
Reading
Bi-focal
Central ADD
Multi-focal
Optimal

FIG. 9B

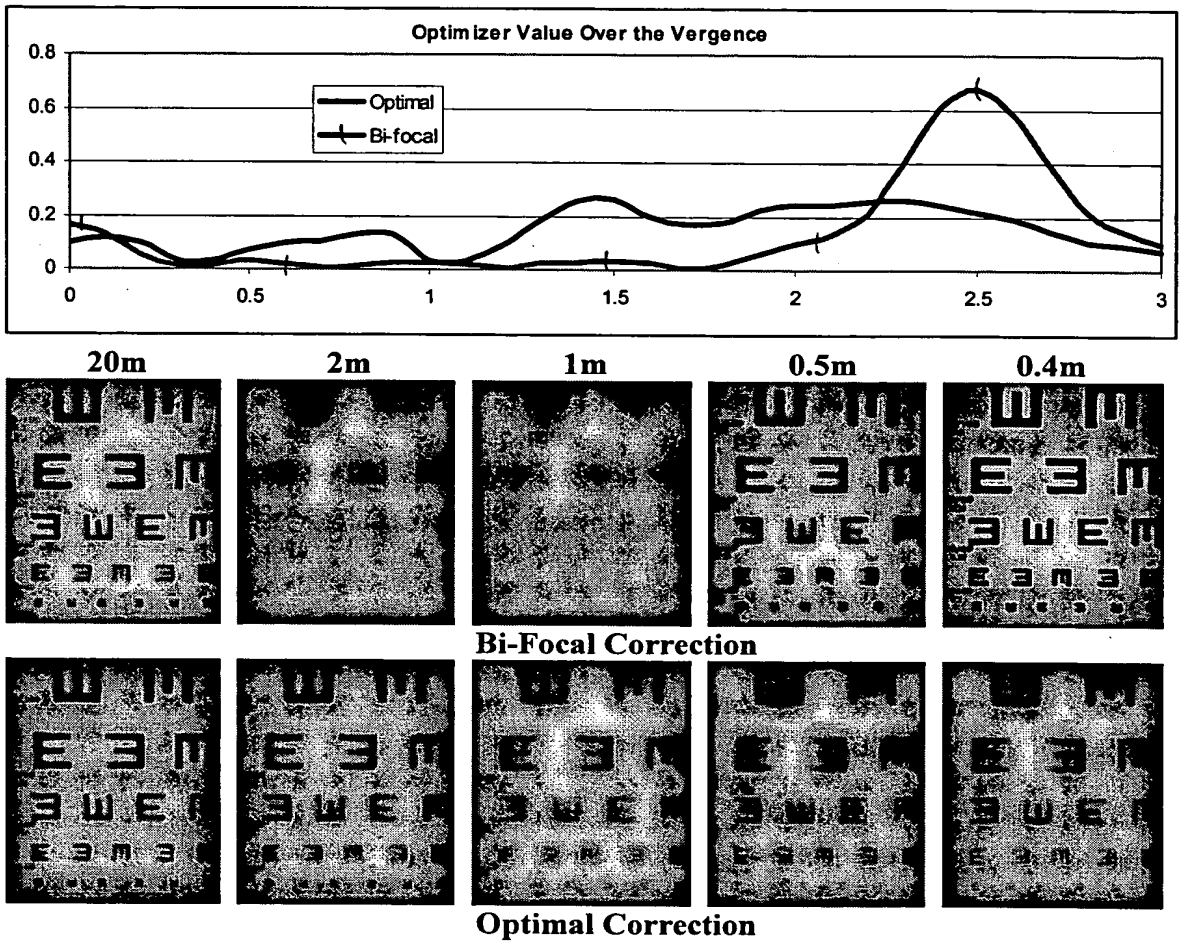

Optimizer Value Over the Vergence
0.8
0.6
0.4
0.2
0
Optimal
Bi-focal
0
0.5
1
1.5
2
2.5
3
20m
2m
1m
0.5m
0.4m
Bi-Focal Correction
Optimal Correction

FIG. 9C

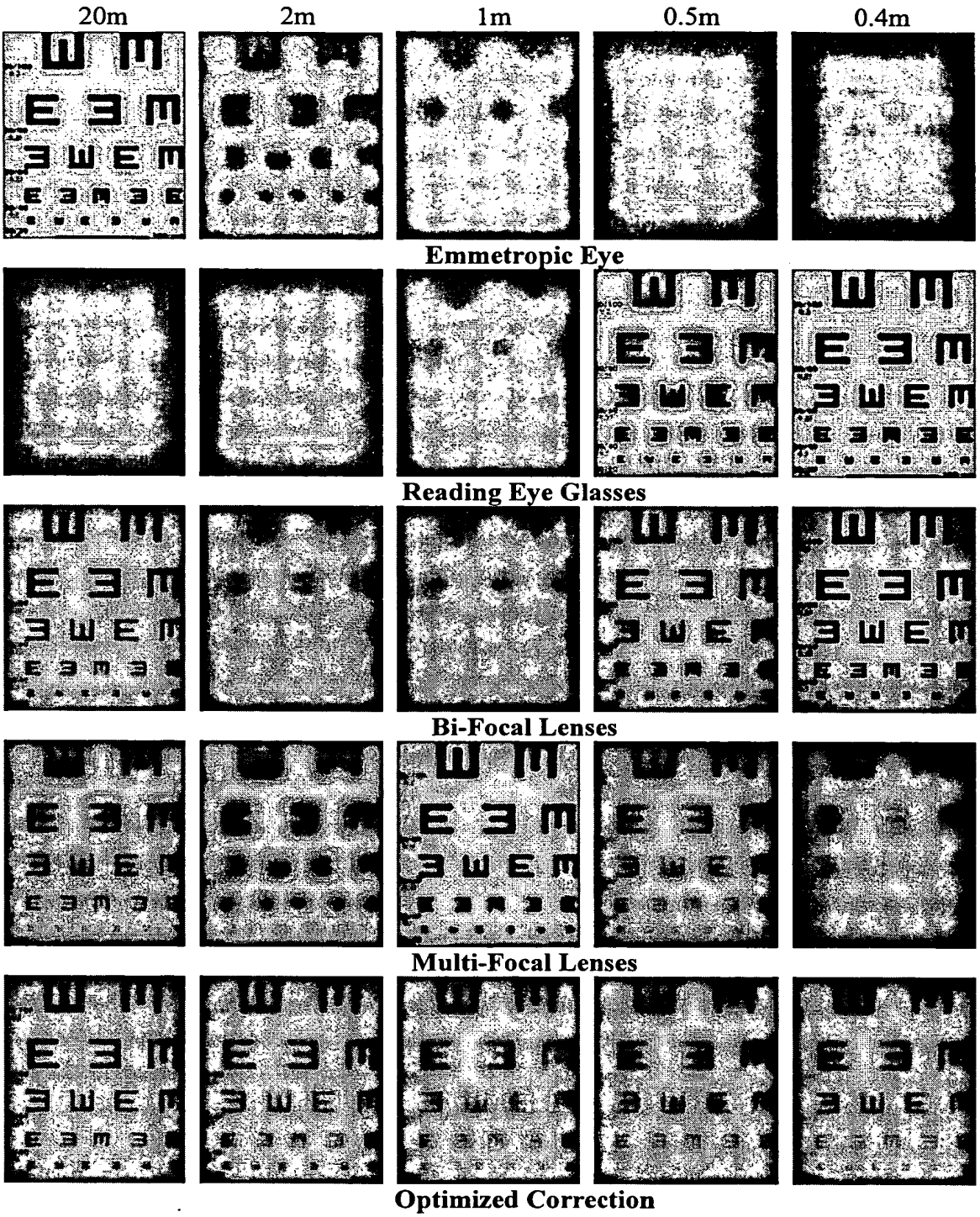
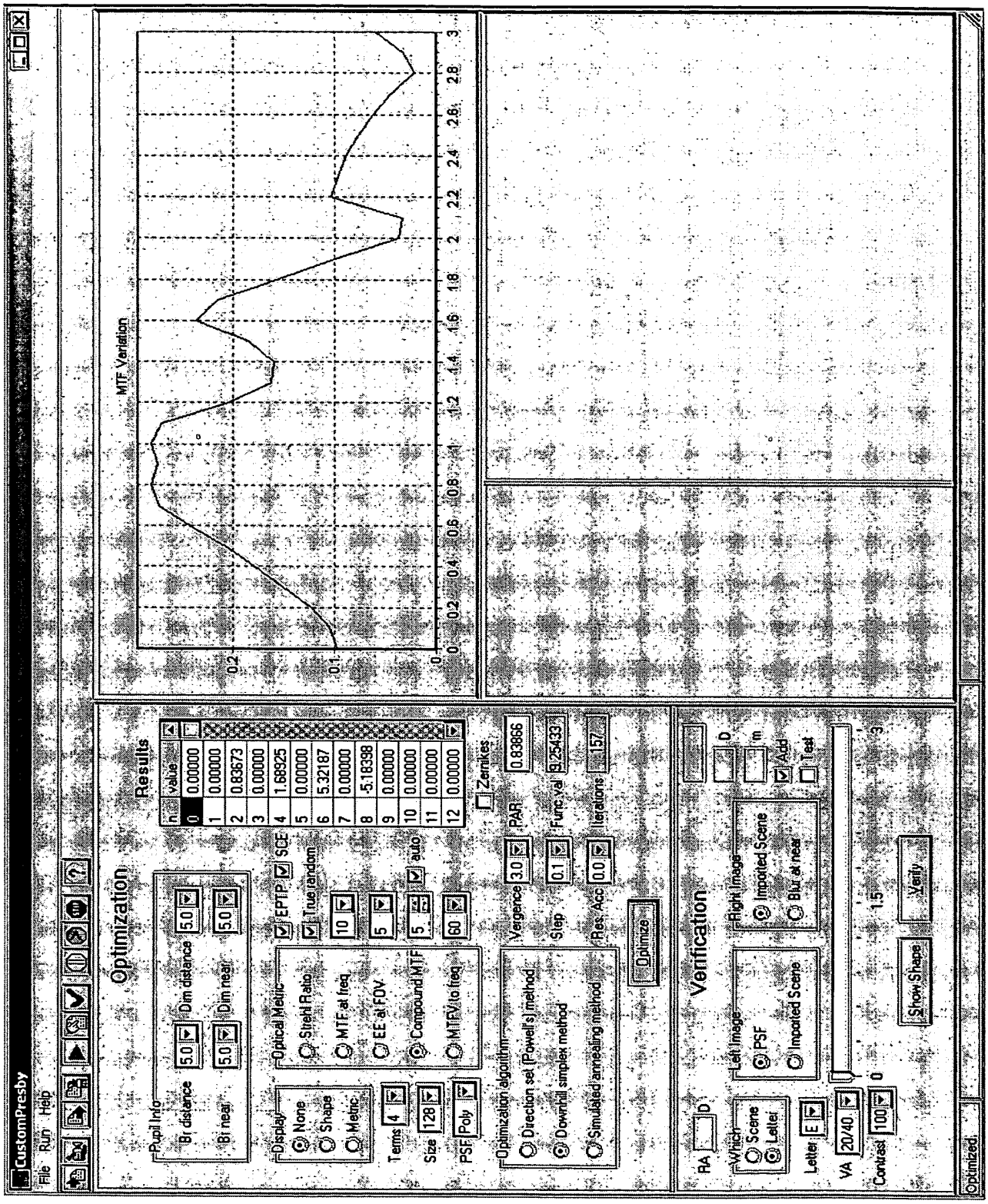
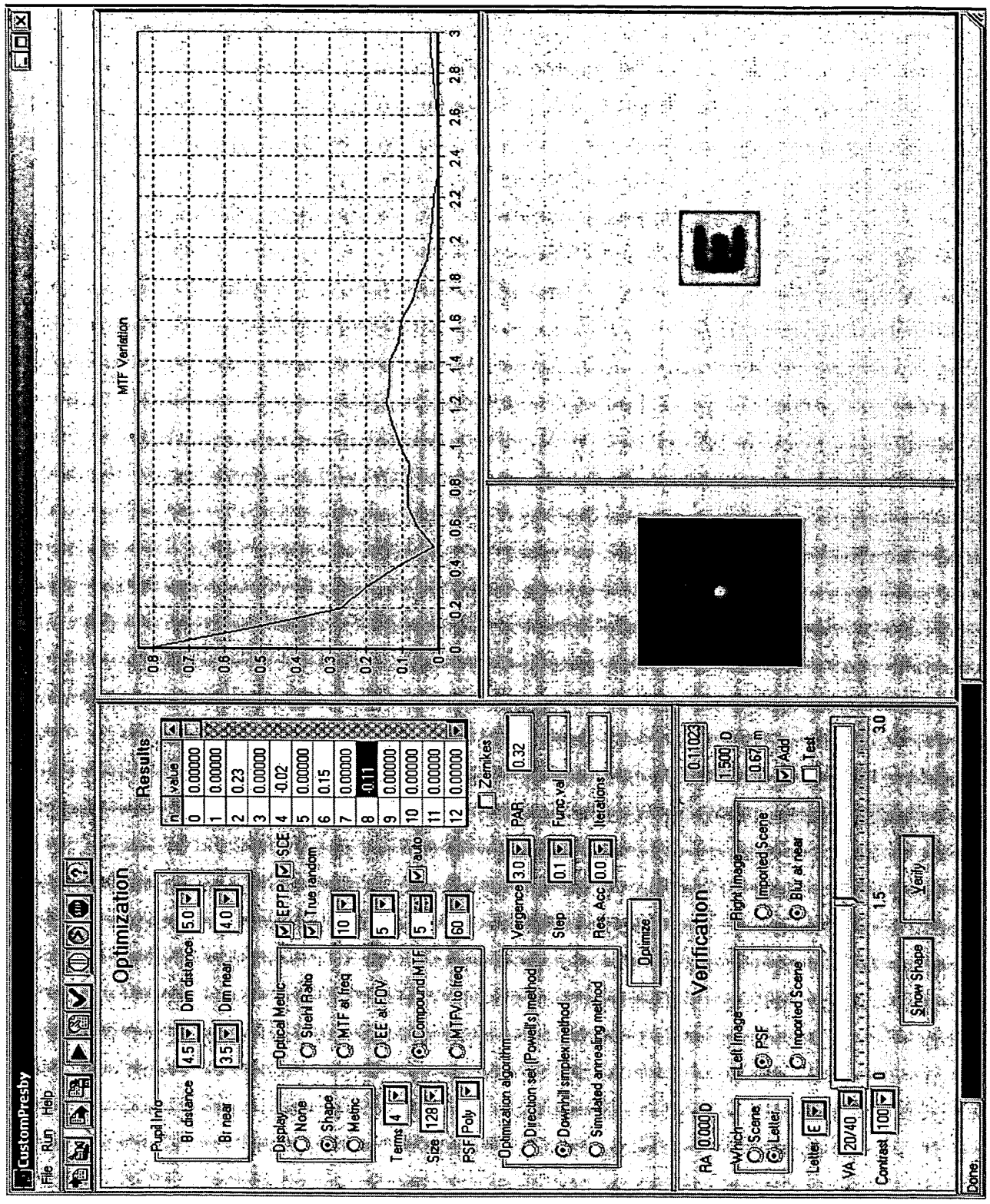

20m
2m
1m
0.5m
0.4m
Emmetropic Eye
Reading Eye Glasses
Bi-Focal Lenses
Multi-Focal Lenses
Optimized Correction

FIG. 10



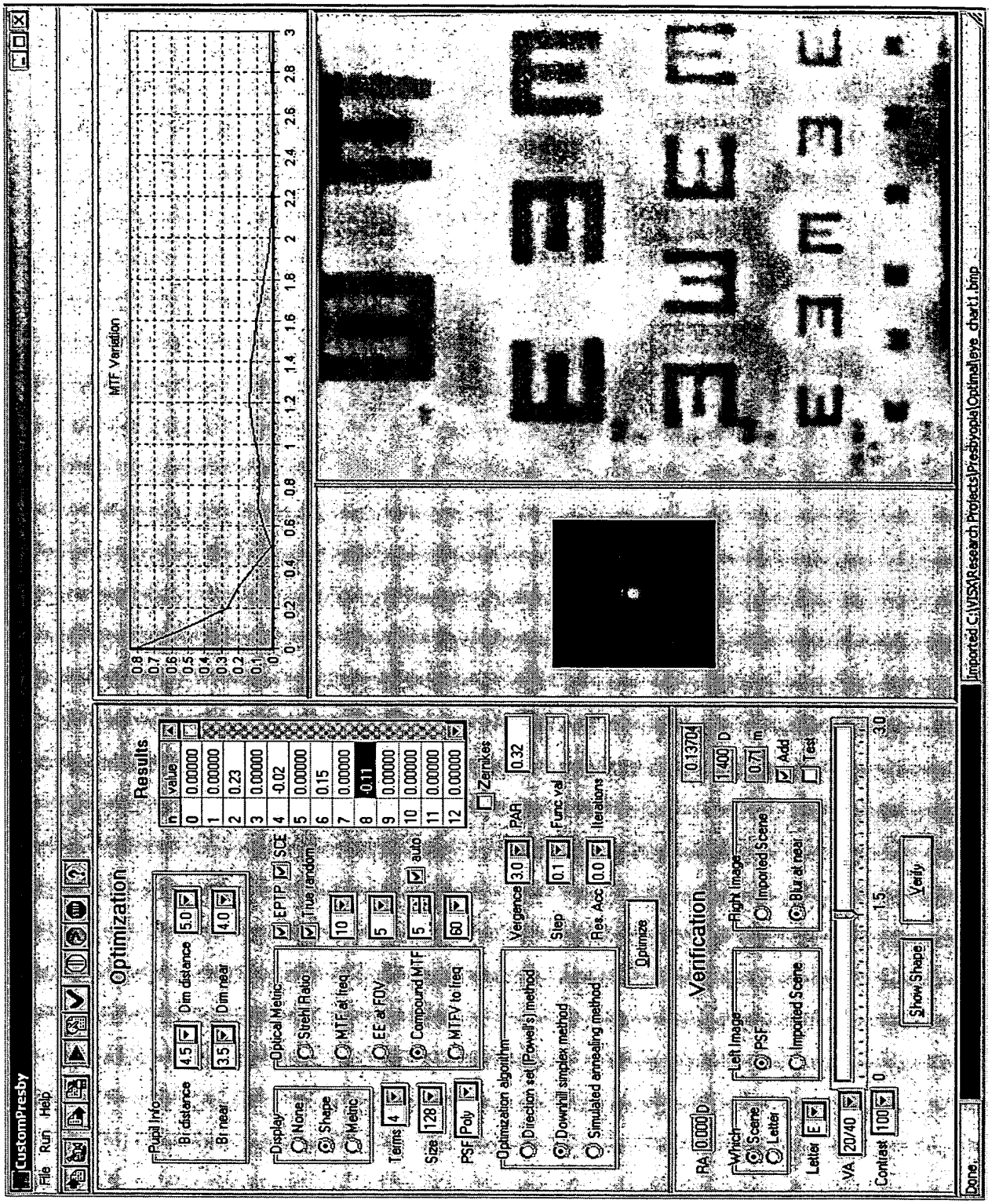
Optimization Interface

FIG. 11



Verification: Single Letter

FIG. 12



Verification: Entire Eye Chart

FIG. 13

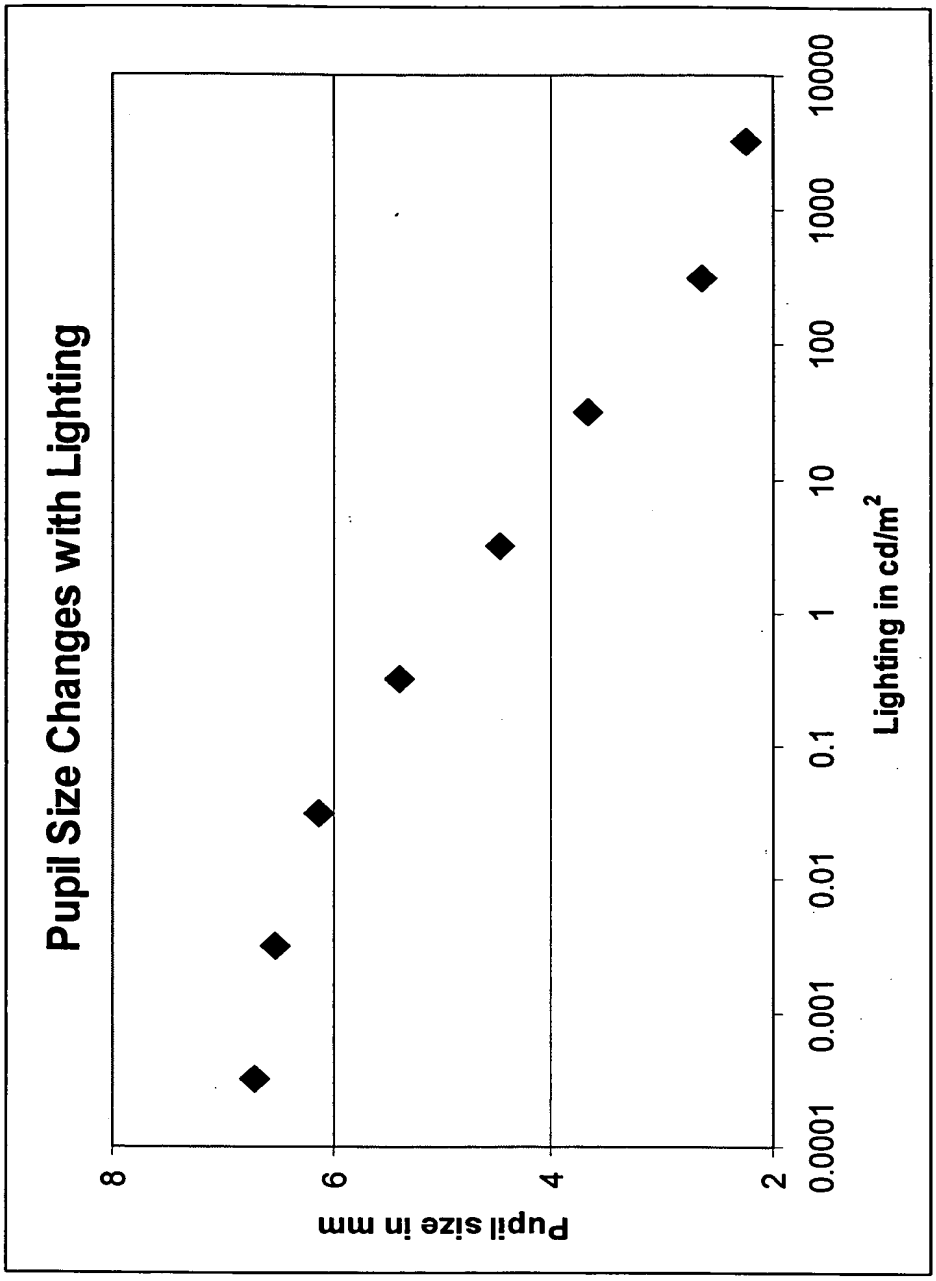

Pupil Size Changes with Lighting
Pupil size in mm
8
6
4
2
Lighting in cd/m2
0.0001
0.001
0.01
0.1
1
10
100
1000
10000

FIG. 14

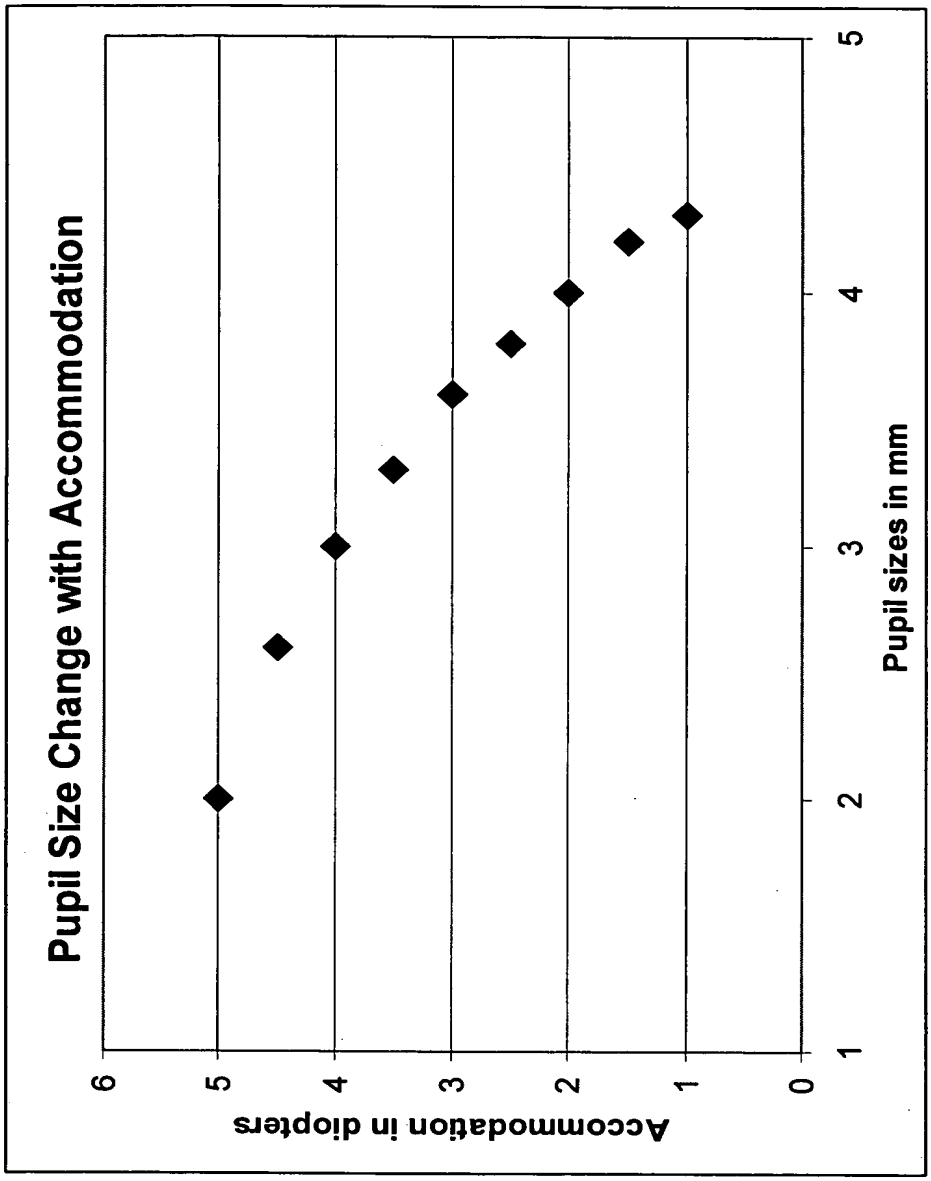

Pupil Size Change with Accommodation
Accommodation in diopters
Pupil sizes in mm
6
5
4
3
2
1
0
1
2
3
4
5

FIG. 15

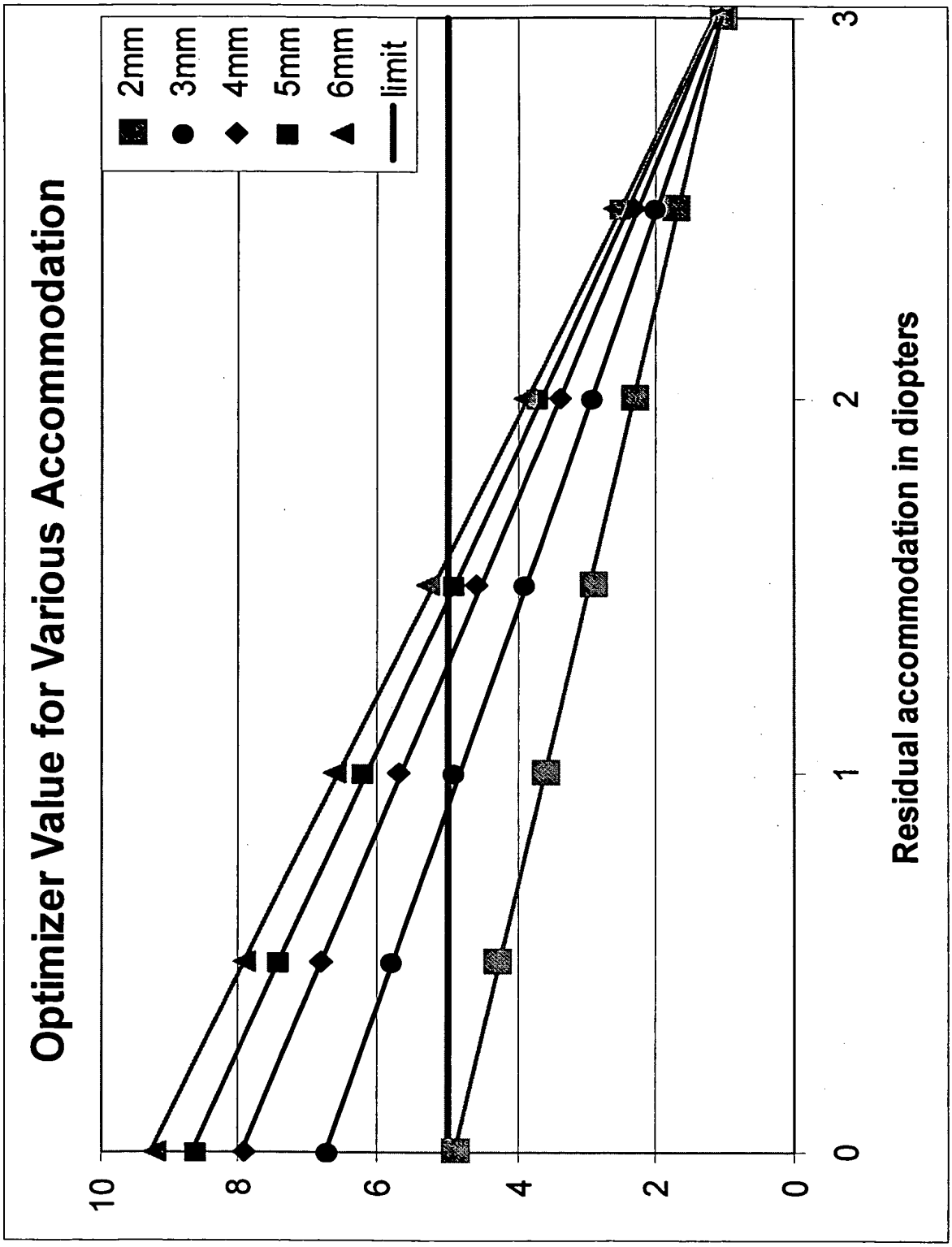

Optimizer Value for Various Accommodation
2mm
3mm
4mm
5mm
6mm
limit
10
8
6
4
2
0
0
1
2
3
Residual accommodation in diopters

FIG. 16

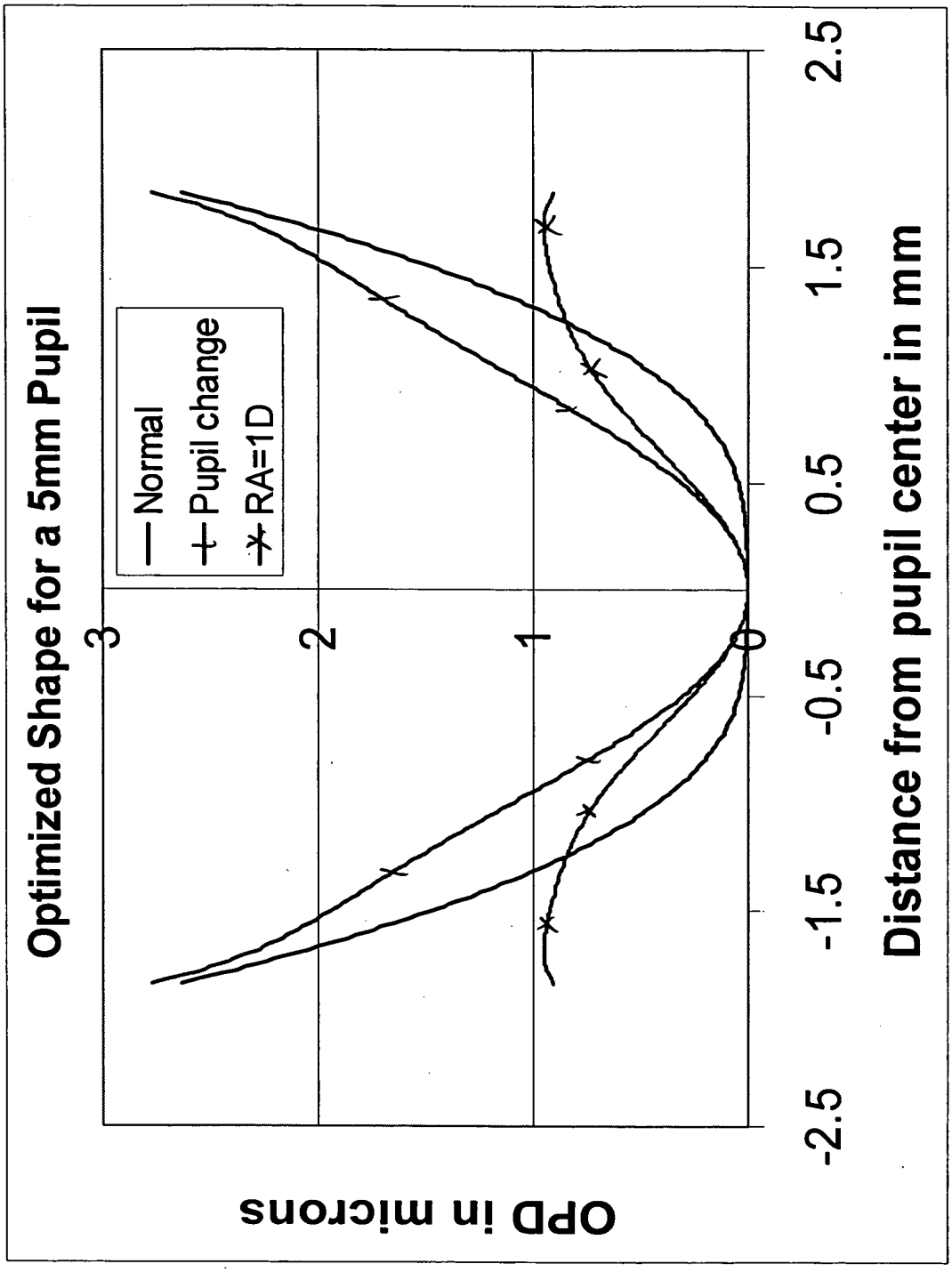

Optimized Shape for a 5mm Pupil
Normal
Pupil change
RA=1D
OPD in microns
3
2
1
0
-2.5
-1.5
-0.5
0.5
1.5
2.5
Distance from pupil center in mm

FIG. 17

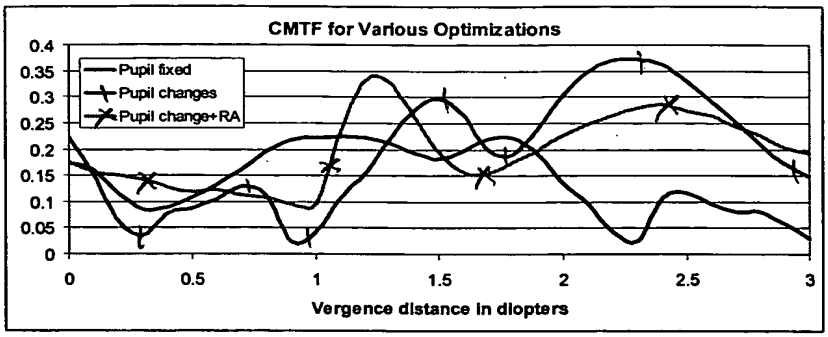


Fig. 18A

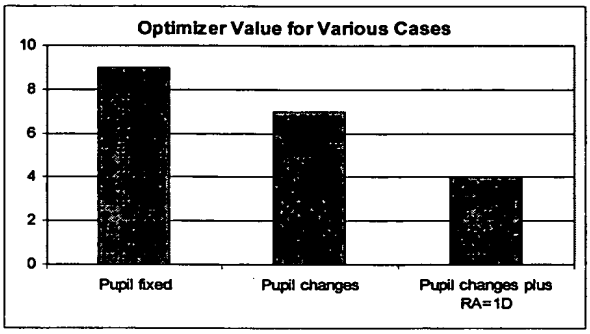


Fig. 18B

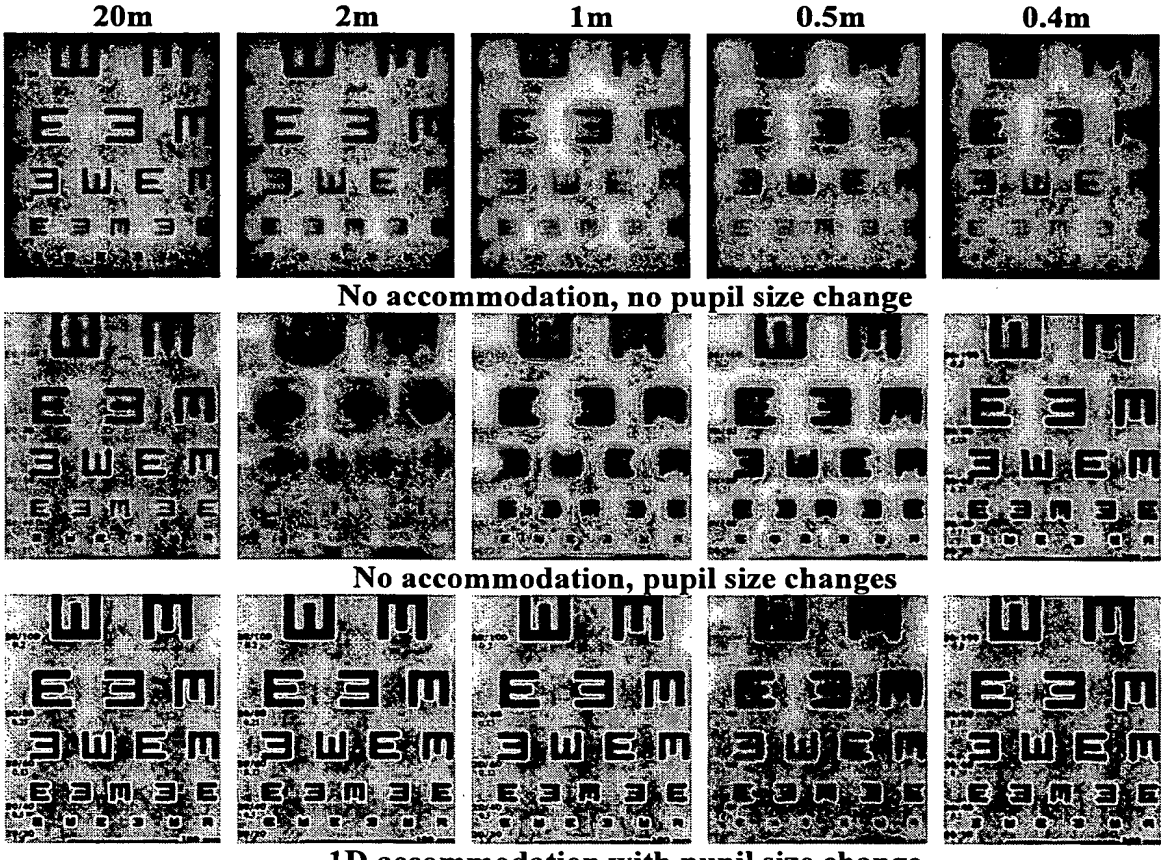
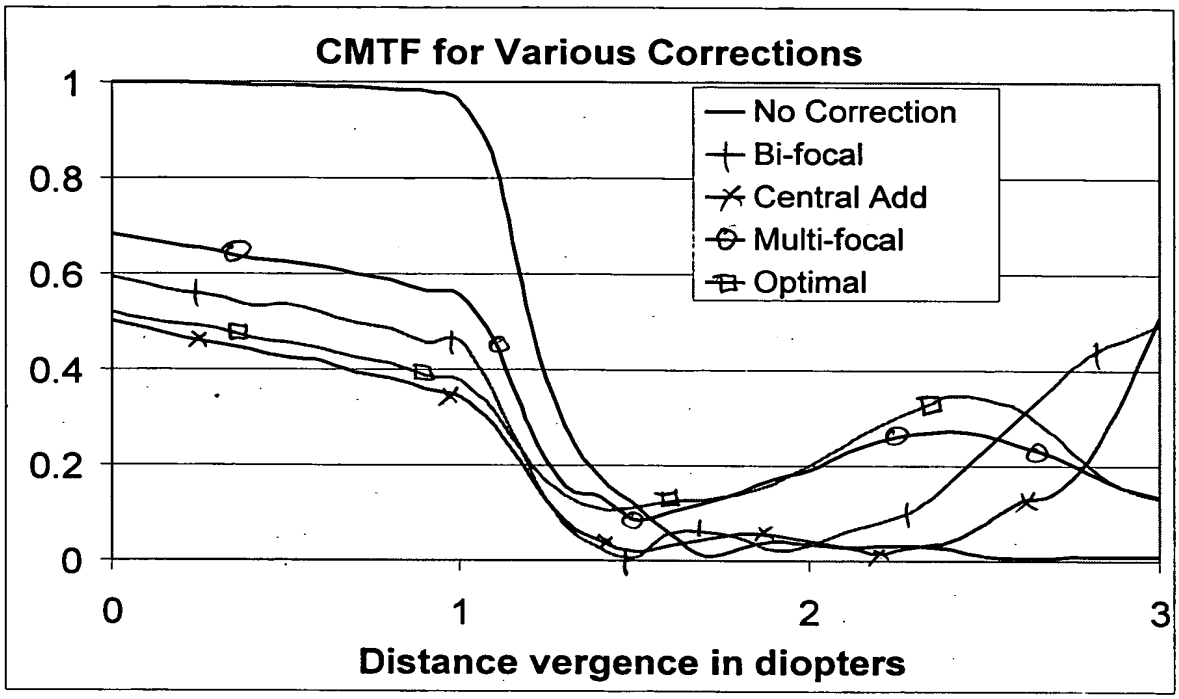


Fig. 18C



Compound MTF (CMTF) with different corrections.

Fig. 19

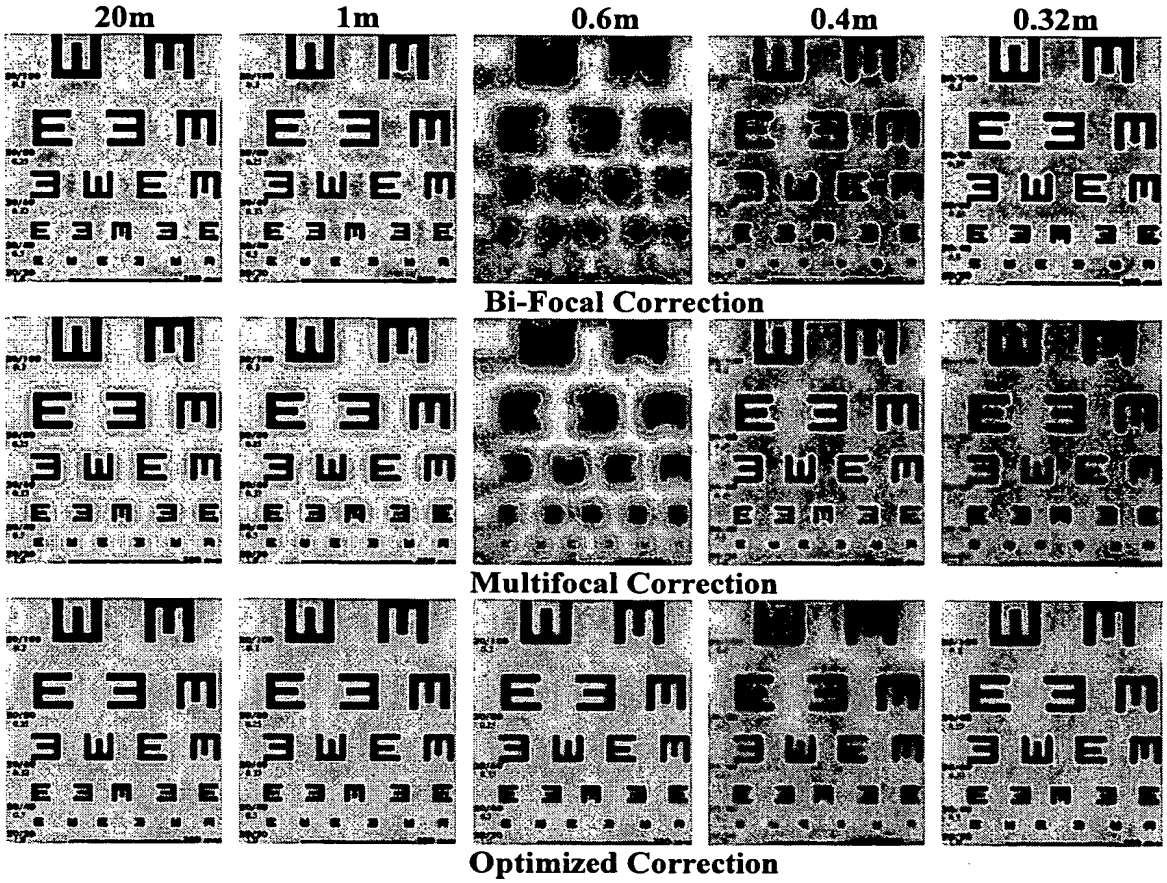

20m
1m
0.6m
0.4m
0.32m
Bi-Focal Correction
Multifocal Correction
Optimized Correction

FIG. 20

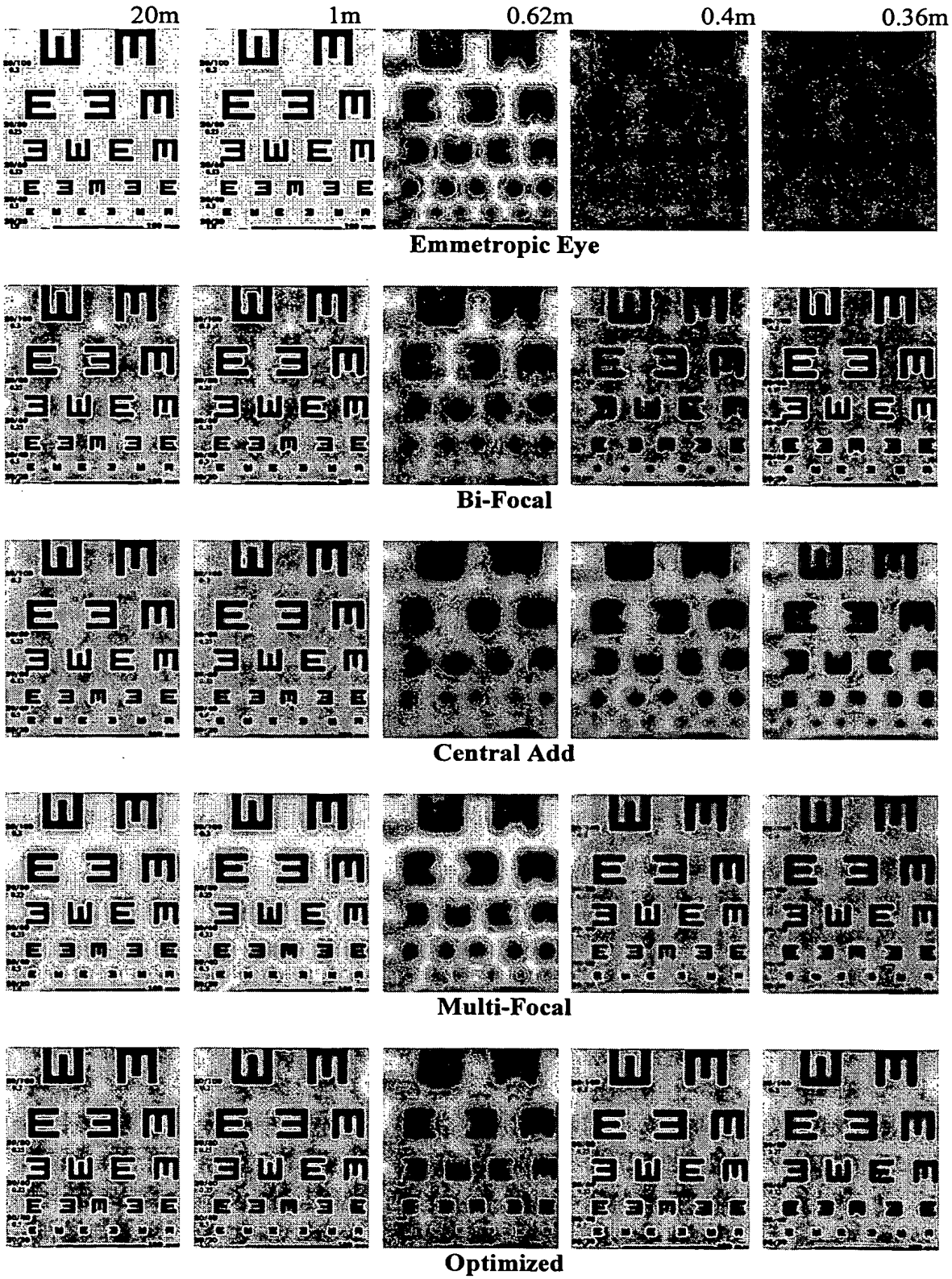

20m
1m
0.62m
0.4m
0.36m
Emmetropic Eye
Bi-Focal
Central Add
Multi-Focal
Optimized

FIG. 21

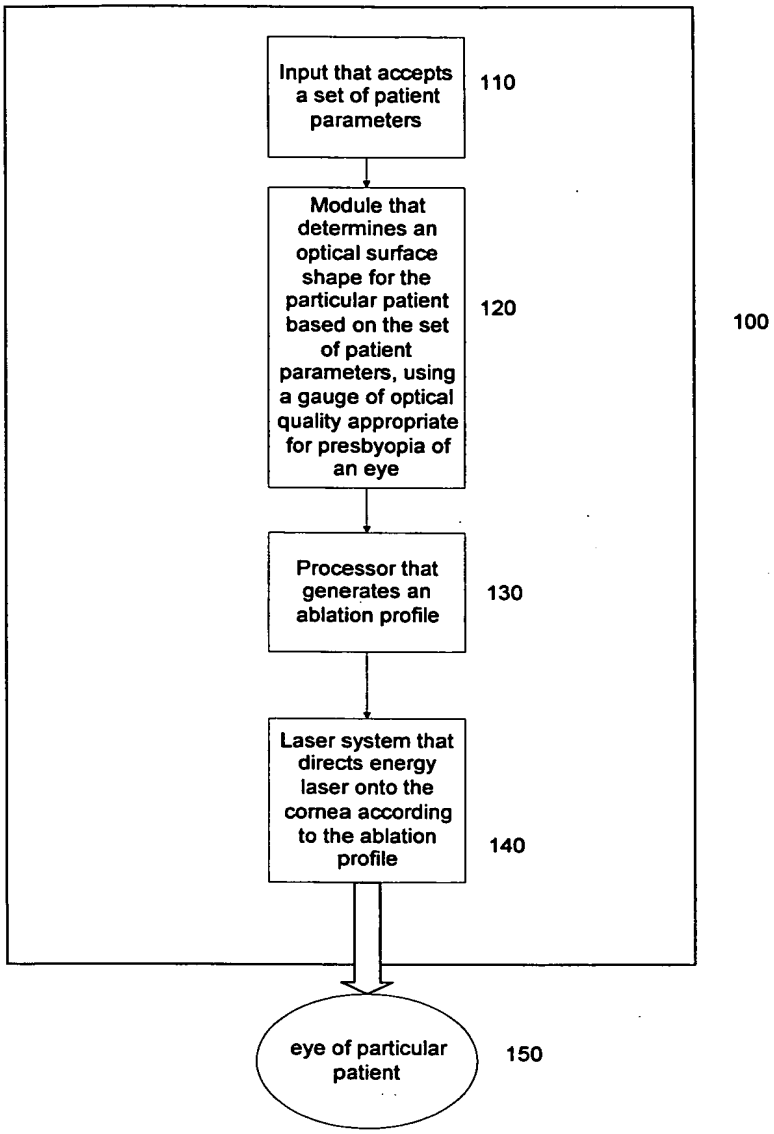

Input that accepts a set of patient parameters
110
Module that determines an optical surface shape for the particular patient based on the set of patient parameters, using a gauge of optical quality appropriate for presbyopia of an eye
120
100
Processor that generates an ablation profile
130
Laser system that directs energy laser onto the cornea according to the ablation profile
140
eye of particular patient
150

FIG. 22

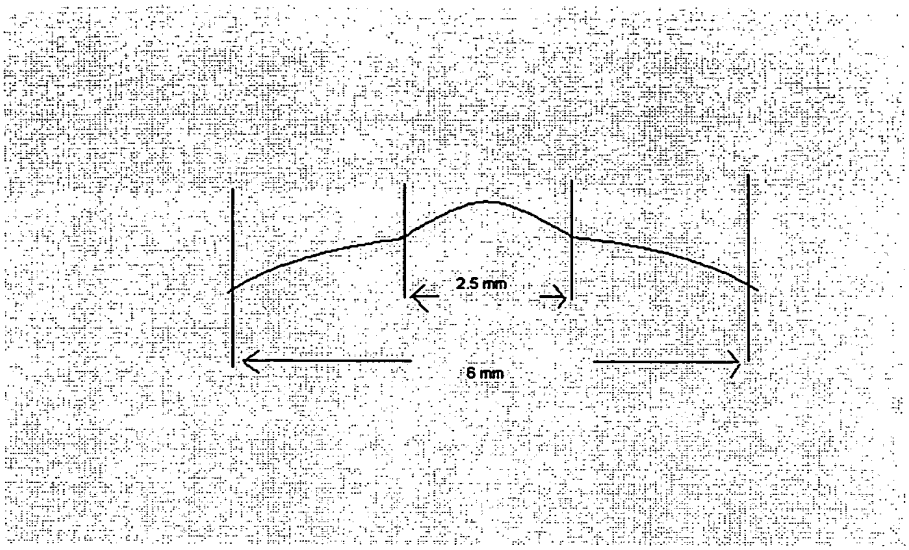


FIG. 23

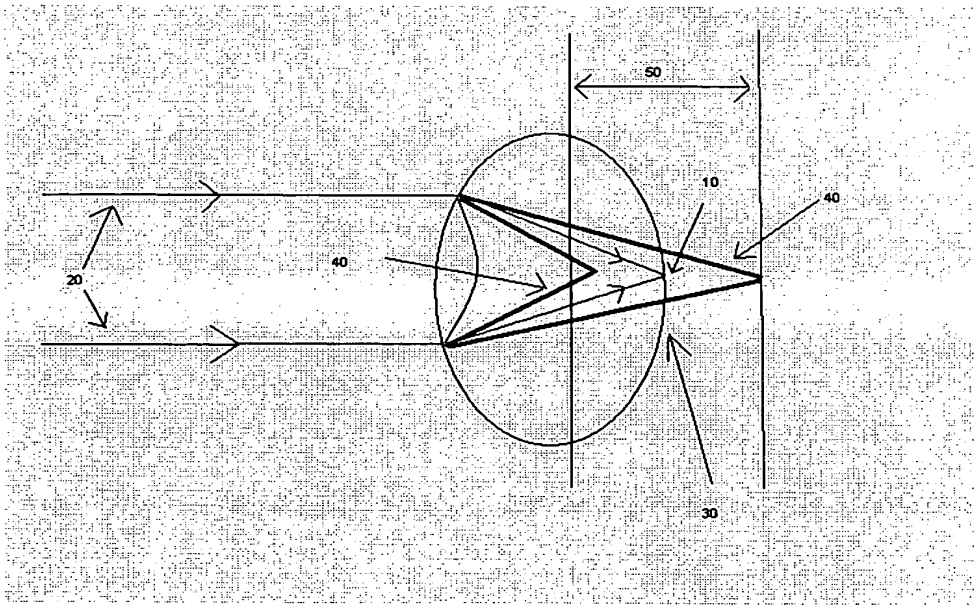


Fig. 24

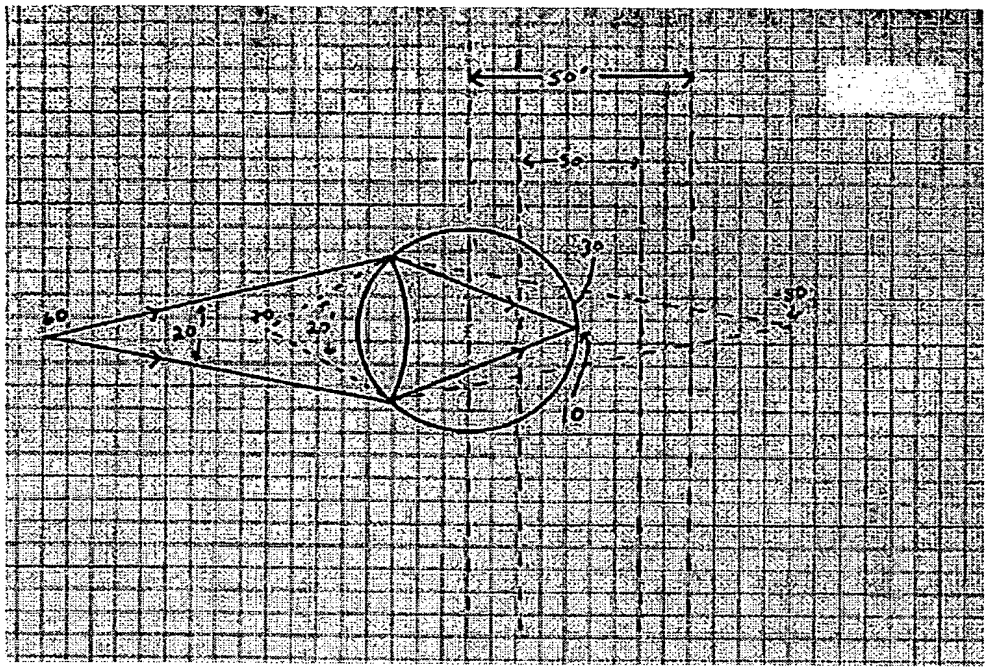

50
50
30
60
20
10
20
10
20
30
10

Fig. 25

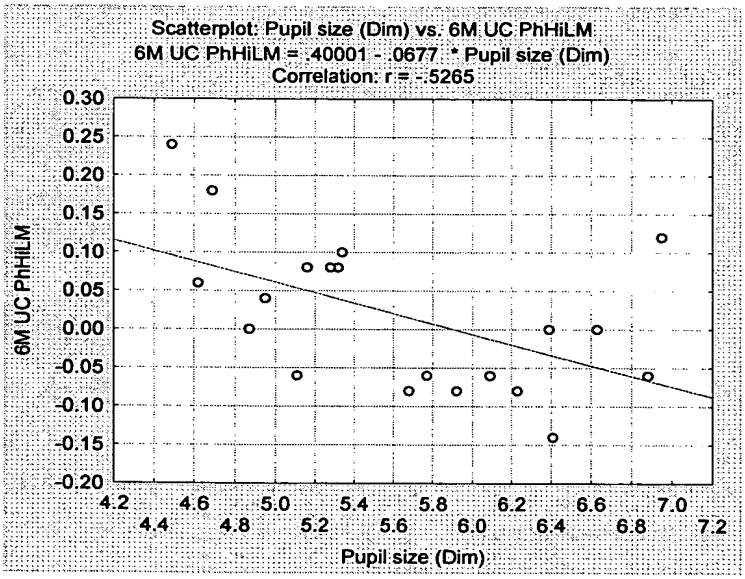

Scatterplot: Pupil size (Dim) vs. 6M UC PhHiLM
6M UC PhHiLM = .40001 - .0677 * Pupil size (Dim)
Correlation: r = -.5265
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
6M UC PhHiLM
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
Pupil size (Dim)

FIG. 26

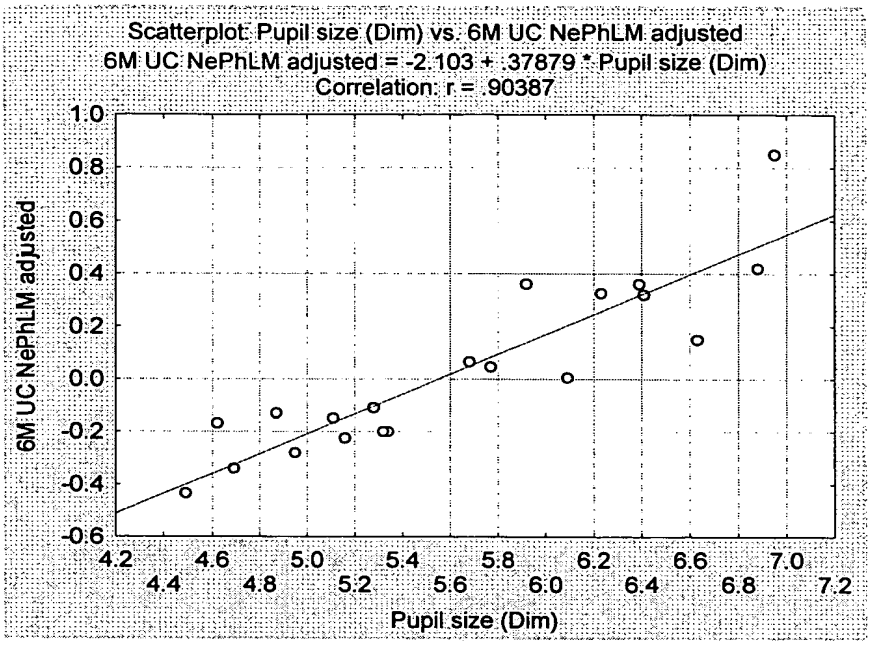

Scatterplot: Pupil size (Dim) vs. 6M UC NePhLM adjusted
6M UC NePhLM adjusted = -2.103 + .37879 * Pupil size (Dim)
Correlation: r = .90387
6M UC NePhLM adjusted
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
Pupil size (Dim)

FIG. 27

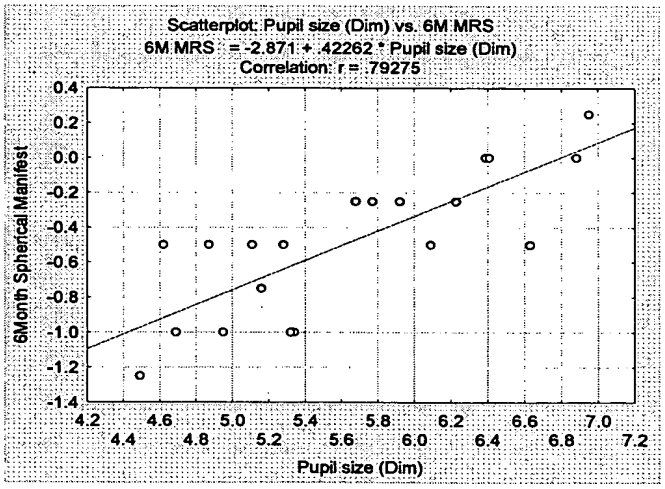

Scatterplot: Pupil size (Dim) vs. 6M MRS
6M MRS = -2.871 + .42262 * Pupil size (Dim)
Correlation: r = .79275
6Month Spherical Manifest
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
Pupil size (Dim)

Fig. 28

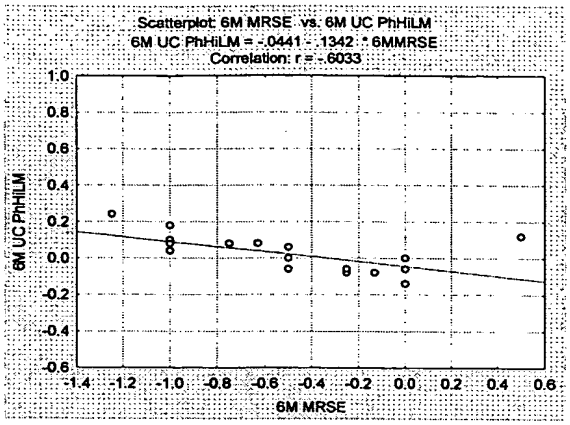


Fig. 29

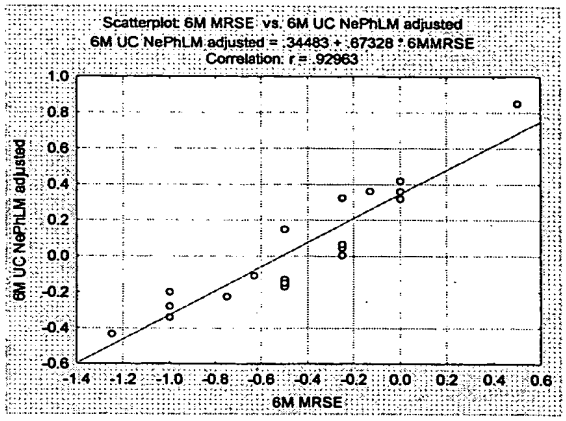


Fig. 30

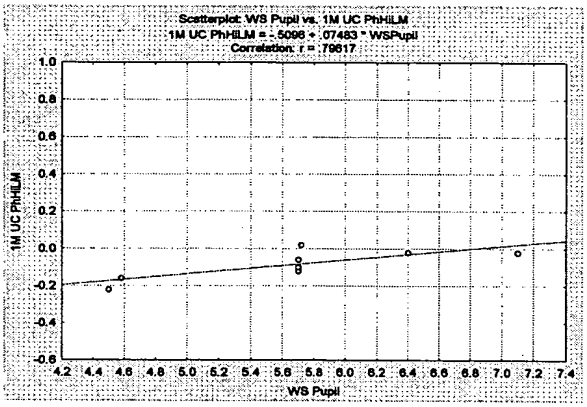


Fig. 31

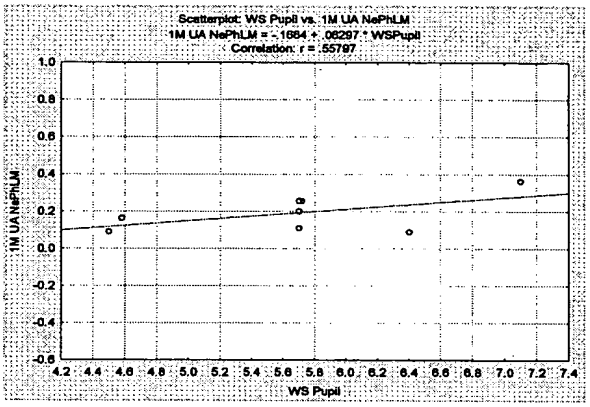


Fig. 32

Group two Near and Distance acuity

These patients have the pupil ratio adjustments. The lines have rotated. Exemplary ideal cases are when the acuities are independent of the pupil size. The values for near acuities are almost independent of pupil size, where there is a small decrease in acuity of larger pupil sizes.

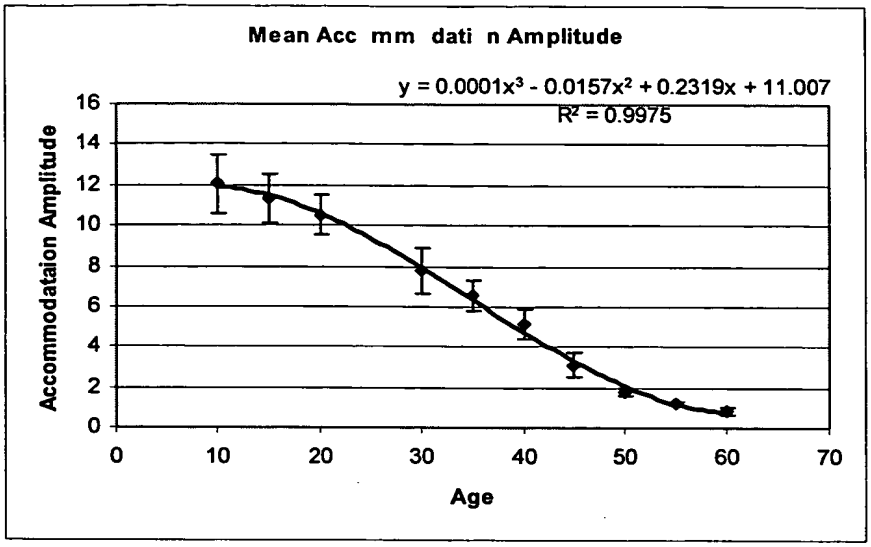

Mean Acc mm dati n Amplitude
y = 0.0001x³ - 0.0157x² + 0.2319x + 11.007
R² = 0.9975
Accommodataion Amplitude
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
Age

Fig. 33

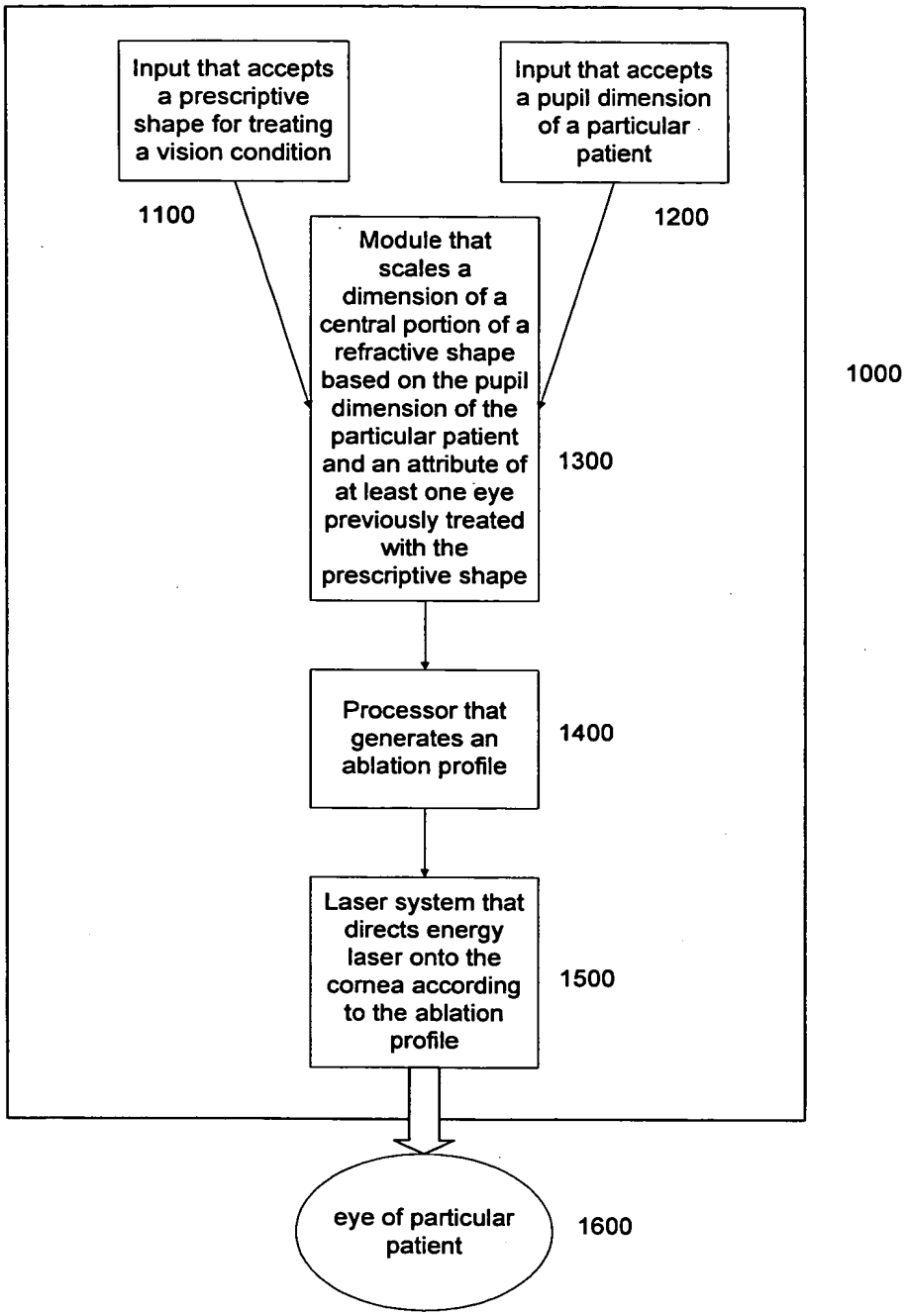

Input that accepts a prescriptive shape for treating a vision condition
1100
Input that accepts a pupil dimension of a particular patient
1200
Module that scales a dimension of a central portion of a refractive shape based on the pupil dimension of the particular patient and an attribute of at least one eye previously treated with the prescriptive shape
1300
1000
Processor that generates an ablation profile
1400
Laser system that directs energy laser onto the cornea according to the ablation profile
1500
eye of particular patient
1600

Fig. 34

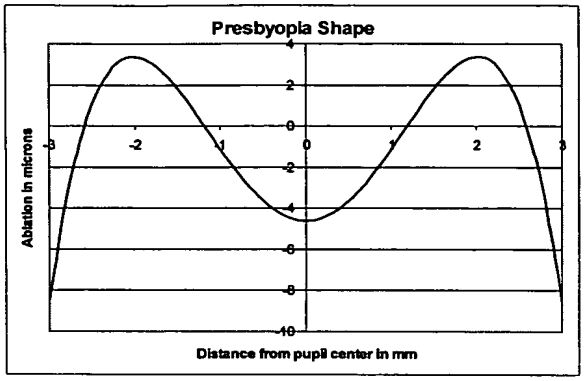


Fig. 35
2-Term solution: presbyopia shape

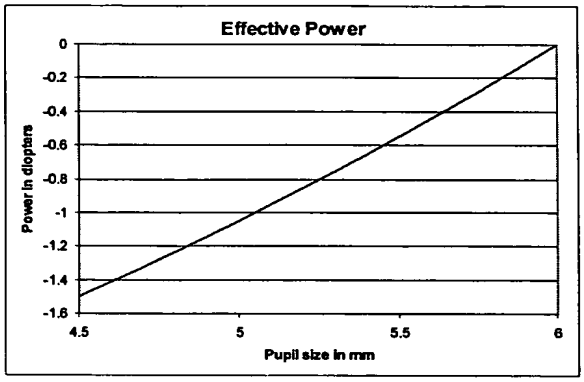


Fig. 36
2-Term Solution: Effective power over a range of pupil sizes (4.5mm to 6mm).

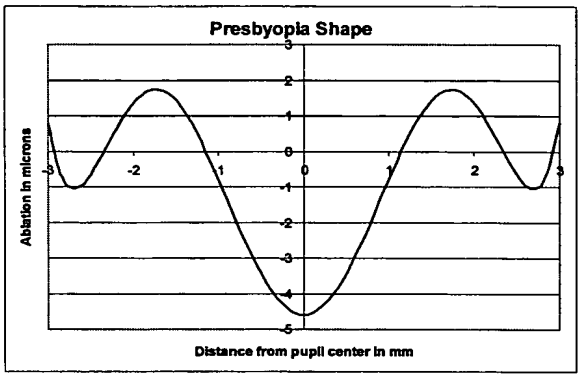


Fig. 37
3-Term solution: presbyopia shape

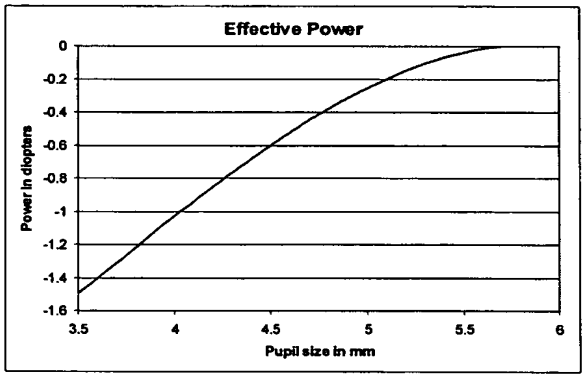


Fig. 38
3-Term solution: effective power over a range of pupil sizes (3.5mm to 6mm).

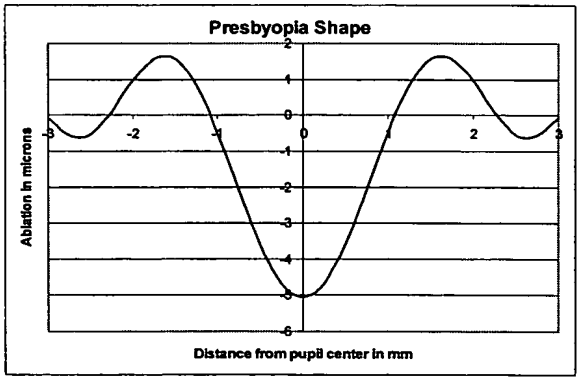


Fig. 39
4-Term solution: presbyopia shape

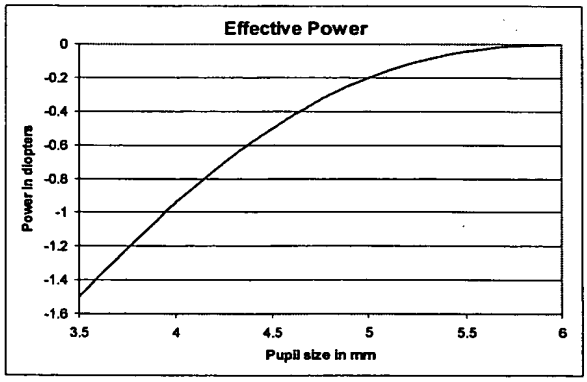


Fig. 40
4-Term solution: effective power over a range of pupil sizes (3.5mm to 6mm).

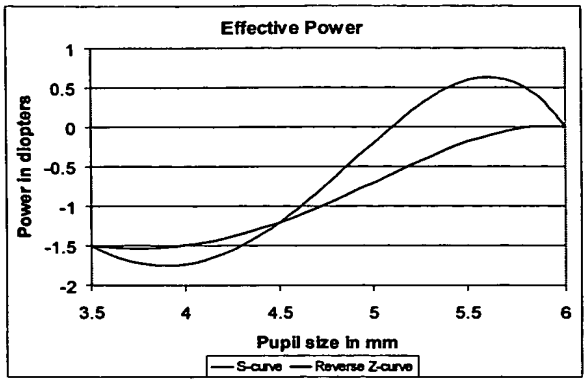


Fig. 41A

Unfavorable S-curve and the favorable reverse Z-curve: effective power

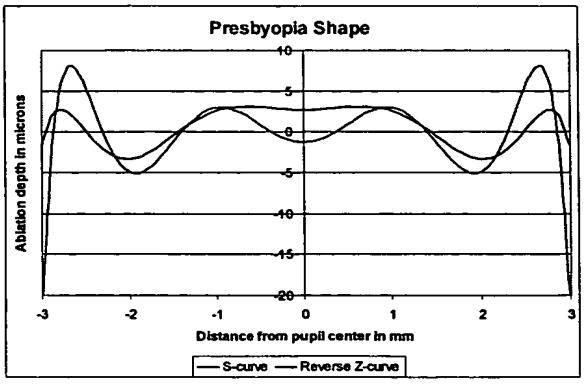


Fig. 41B

Unfavorable S-curve and the favorable reverse Z-curve: presbyopia shapes

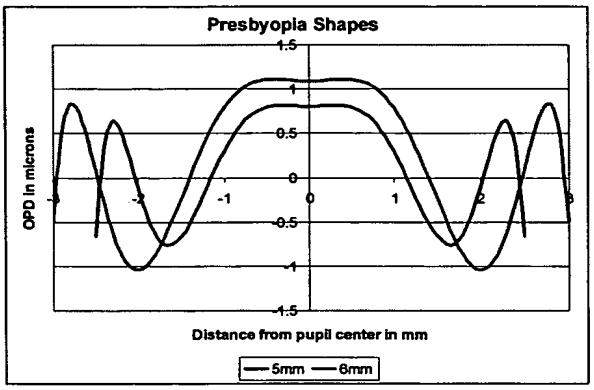


Fig. 42 Examples of Presbyopia Shapes for a 5mm and a 6mm pupil.

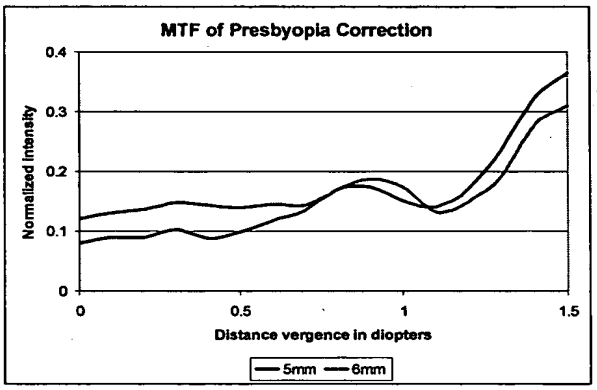


Fig. 43 Examples of Modulation Transfer Function (MTF) for a 5mm and a 6mm pupil.

5 mm pupil

6 mm pupil

Fig. 44

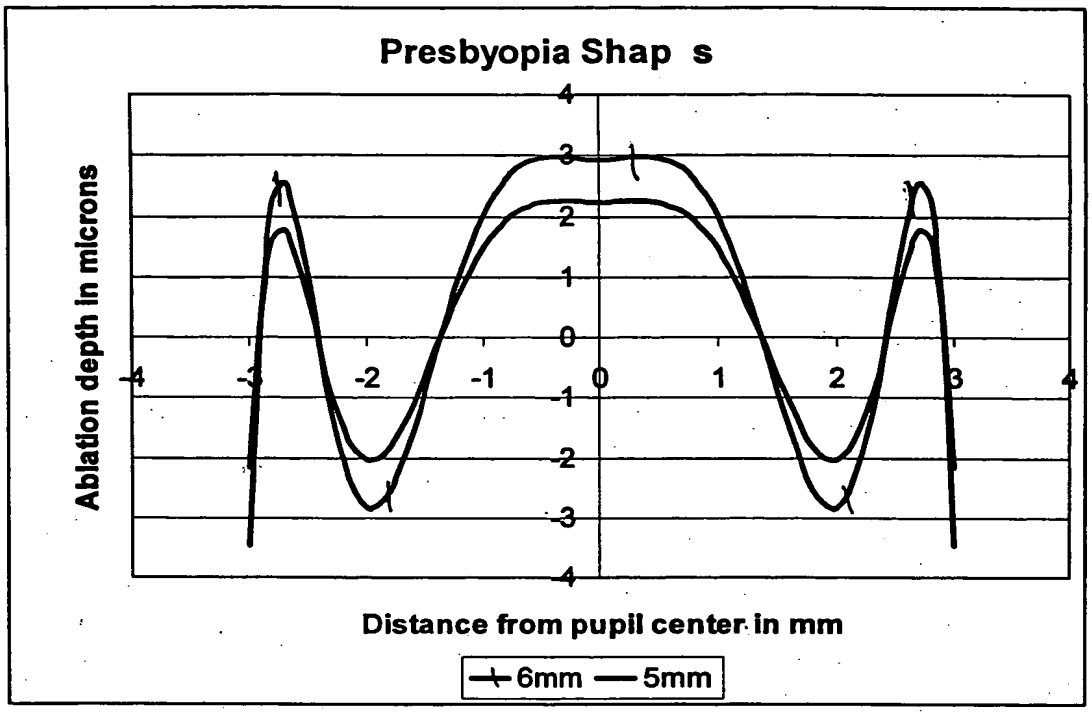


FIG_45B

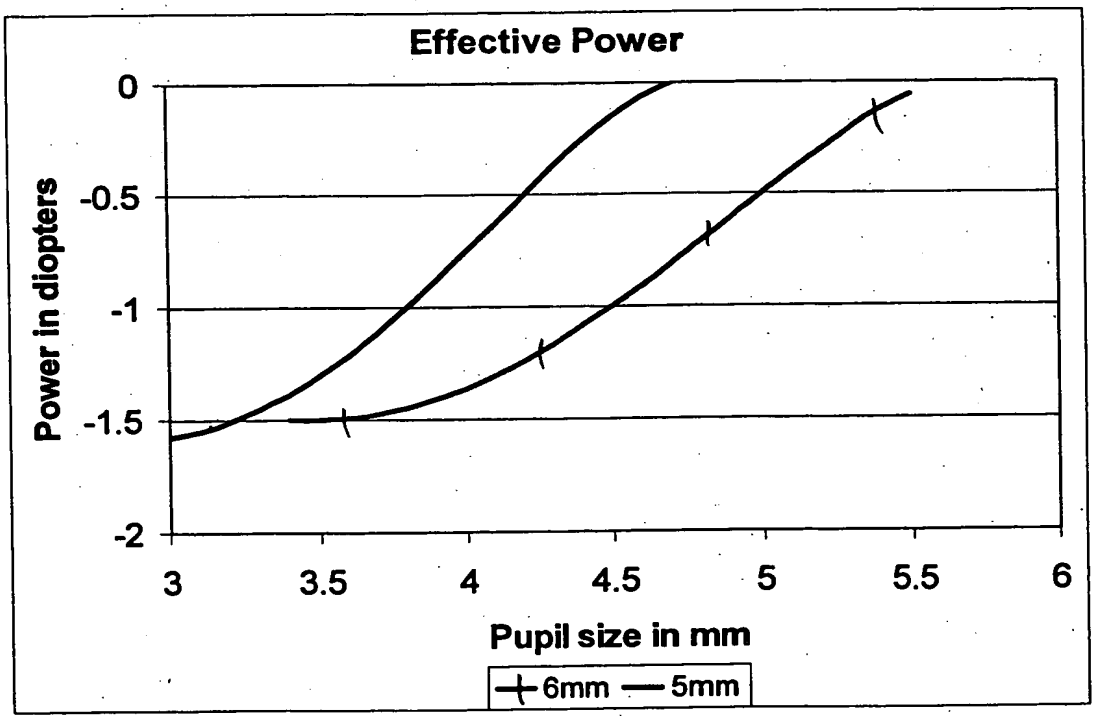


FIG_45A